Technical Report 897

Specifying Skill-Based Training Strategies and Devices: A Model Description

Paul J. Sticha and Mark Schlager
Human Resources Research Organization

Dennis M. Buede
Decision Logistics, Inc.

Kenneth Epstein
Consultant

H. Ric Blacksten
Human Resources Research Organization

June 1990

United States Army Research Institute for the Behavioral and Social Sciences

Technical Report 897

Specifying Skill-Based Training Strategies and Devices: A Model Description

Paul J. Sticha and Mark Schlager
Human Resources Research Organization

Dennis M. Buede
Decision Logistics, Inc.

Kenneth Epstein
Consultant

H. Ric Blacksten
Human Resources Research Organization

PM TRADE Field Unit at Orlando, Florida
Stephen L. Goldberg, Chief

Training Research Laboratory
Jack H. Hiller, Director

U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
Department of the Army

June 1990

Army Project Number
2Q263007A795

Training Simulation

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS --
2a. SECURITY CLASSIFICATION AUTHORITY -- 2b. DECLASSIFICATION/DOWNGRADING SCHEDULE --	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.
4. PERFORMING ORGANIZATION REPORT NUMBER(S) FR-PRD-90-01	5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Technical Report 897
6a. NAME OF PERFORMING ORGANIZATION Human Resources Research Organization (HumRRO) 6b. OFFICE SYMBOL (If applicable) --	7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute PM TRADE Field Unit
6c. ADDRESS (City, State, and ZIP Code) 1100 S. Washington Street Alexandria, VA 22314	7b. ADDRESS (City, State, and ZIP Code) 12350 Research Parkway Orlando, FL 32826-3276
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences 8b. OFFICE SYMBOL (If applicable) PERI-I	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER C: N61339-89-C-0041
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 63007A PROJECT NO. 795 TASK NO. 3104 WORK UNIT ACCESSION NO. C3

11. TITLE (Include Security Classification)
Specifying Skill-Based Training Strategies and Devices: A Model Description

12. PERSONAL AUTHOR(S) Sticha, Paul J.; Schlager, Mark (HumRRO); Buede, Dennis (Decision Logistics); Blacksten, H. Ric (HumRRO); Epstein, Kenneth (independent consultant)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM 89/03 TO 90/01	1990, June	

16. SUPPLEMENTARY NOTATION
Contracting Officer's Representative, Stephen L. Goldberg

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Training system optimization; Training system model; Skill training; Skill identification; Skilled performance

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report describes the background and specifications of a model that identifies the skills required for competent performance of a job, specifies strategies for training those skills, defines training devices, and evaluates efficient use of skill-based training devices. The framework addresses three benefits of skill training: (1) skill training provides more practice on critical skills in a given amount of time, (2) critical skills generalize to many tasks, and (3) training the critical skills involved in complex and difficult tasks decreases the mental workload required to learn or perform the tasks.

Both a formal model and a concrete example of the steps derived from that theoretical approach in the context of the Air Traffic Control job domain are described. The specification of training strategies and devices is broken into four steps: identifying skills, selecting instructional strategies, designing devices, and allocating training. First, tasks are reduced to their elements to identify the general abilities and domain-specific skills required. Second, skills are grouped and sequenced for training. Third, device interface
(Continued)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Michael J. Singer	22b. TELEPHONE (Include Area Code) (407) 380-4387 22c. OFFICE SYMBOL PERI-IF

DD Form 1473, JUN 86 Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

ARI Technical Report 897

19. ABSTRACT (Continued)

and instructor support requirements are derived for the target skills. Finally, the projected cost of task training is compared to task training supplemented by the proposed skill training.

FOREWORD

The cost of training devices and simulators is not a trivial factor in training. The capability for simulating reality is also increasing on an annual basis. The military must determine exactly how much simulation is sufficient for the learning objectives. Behavioral and analytical techniques that can quickly and easily project or predict simulation and training device requirements are lacking. In addition, information on the cost-effective use of training equipment within courses of instruction is sparse. The development of models, databases, and techniques addressing these problems is the first step toward providing integrated behavioral and engineering decisions in designing, fielding, and using advanced training technology. The potential effect on the Army is to reduce the cost of training equipment while increasing the equipment's instructional effectiveness.

In order to address these concerns and problems, the Army Research Institute for the Behavioral and Social Sciences (ARI) and the Project Manager for Training Devices (PM TRADE) have joined efforts (MOU of Technical Coordination, May 83; MOU Establishing the ARI Orlando Field Unit, Mar 85; Expanded MOU, July, 86). Task number 3104, Advanced Technology for the Design of Training Devices and Simulators provided the framework for the work reported in this document. PM TRADE has been completely informed of the development of the models and analytical techniques. The models and techniques developed in this effort are expected to provide the basis for useful aids supporting the integration of behavioral and engineering data, knowledge, and expertise in training equipment design in the future.

EDGAR M. JOHNSON
Technical Director

SPECIFYING SKILL-BASED TRAINING STRATEGIES AND DEVICES: A MODEL DESCRIPTION

EXECUTIVE SUMMARY

Requirement:

The overall Army need is to develop models that can help specify effective and efficient training devices and strategies so that training requirements are met at the lowest possible cost, or the highest overall performance may be obtained at a specified cost. Previous efforts have examined this need from a task-based orientation. There was a need to describe model procedures that could identify the skills required for competent job performance, specify strategies for training these skills, design training devices to implement the skill-based training strategies, and evaluate the most efficient use of skill-based training devices.

Procedure:

The approach consisted of three major tasks. The first task specified the requirements of the model, its users, and its major components in order to set the boundaries of the approach. The second step reviewed the research literature, addressing the definition of skills, the organization of skill categories, and the effectiveness of skill-training strategies. The third step developed a formal model for specifying skill-based training strategies and devices, based on the knowledge and theory identified in the first two steps.

Findings:

The model framework developed in the project identifies three benefits of skill training. First, skill training can provide much more practice on a critical skill in a given amount of time or for a given cost. Second, critical skills can generalize to many tasks, so that training the skill can avoid unnecessary and redundant task training. Third, training the critical skills involved in complex and difficult tasks can decrease the mental workload required to perform the tasks, and consequently speed up subsequent task learning.

The formal model breaks the specification of training strategies and devices into four steps: identifying skills, selecting instructional strategies, designing devices, and allocating training. The primary objective of the first step is to decompose tasks into their elements (i.e., performing actions upon objects), to identify the general abilities that enable the performer to accomplish the task, and to describe the domain-specific skills that will become candidates for skill-based training. The main goal of the second step is to group and sequence skills for training. In the third step, device requirements are derived from the nature of the skills to be taught. These requirements include instructional capabilities and interface features. The final activity compares the projected cost of task training to that of task training supplemented by the proposed skill training. A concrete example from the Air Traffic Control domain illustrates the steps derived from the theoretical approach in the context of a real job domain.

Use of Findings:

The procedures developed in this effort can be used to help training developers understand the benefits of skill training, identify effective skill-training strategies, and plan the efficient implementation of these strategies using training devices. The described model can form the basis of an automated aid for the design of skill-based training devices. Finally, the model development identified several needs for future basic and applied research.

SPECIFYING SKILL-BASED TRAINING STRATEGIES AND DEVICES: A MODEL DESCRIPTION

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Technical Director

JON W. BLADES
COL, IN
Commanding

Research accomplished under contract for
the Department of the Army

Human Resources Research Organization

Technical review by

Michael J. Singer
Paul J. Tremont

NOTICES

~~**DISTRIBUTION**: Primary distribution of this report has been made by ARI. Please address correspondence concerning distribution of reports to: U.S. Army Research Institute for the Behavioral and Social Sciences, ATTN: PERI-POX, 5001 Eisenhower Ave., Alexandria, Virginia 22333-5600.~~

FINAL DISPOSITION: This report may be destroyed when it is no longer needed. Please do not return it to the U.S. Army Research Institute for the Behavioral and Social Sciences.

NOTE: The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

SPECIFYING SKILL-BASED TRAINING STRATEGIES AND DEVICES: A MODEL DESCRIPTION

INTRODUCTION

This report describes an effort to develop model procedures to identify the skills required for competent job performance, to specify strategies for training these skills, to design training devices to implement the skill-training strategies, and to evaluate the most efficient use of skill-based training devices. A skill-based training device may tutor, instruct, or present new material to the student regarding critical skills with little or no representation of the job domain, missions, systems, or environments. Examples of skills that might be trained in such devices are reading radar symbols, identifying vehicles, applying tactical decision rules, and using test equipment for troubleshooting. These skills apply to many kinds of tasks; they are not tasks themselves. The overriding goal of these methods is to specify training strategies and devices that make training more effective and efficient, so that training requirements are met at the lowest possible cost, or the highest overall performance may be obtained at a specified cost.

This effort consisted of three major tasks. The first task specified the requirements of the model, its users, and its major components. The second task reviewed the research literature addressing the definition of skills, the organization of skill categories, and the effectiveness of skill-training strategies. The third task developed a detailed model of the components identified in the first task. The results and conclusions of the review are presented in the second section of the report. The third section of the report presents a rationale for skill-based training. The fourth section presents an example that describes the model in the context of tasks and skills drawn from air traffic control. A detailed description of the developed model is presented using IDEF0 (Integrated Computer Aided Manufacturing Definition) methodology.

Background

Skilled operation and maintenance of military equipment requires considerable training. The Army spends approximately $2 billion annually so that soldiers may acquire and maintain the specialized skills (including flight skills) required to conduct the Army mission (Office of the Assistant Secretary of Defense (Force Management and Personnel), 1989). Because of the magnitude of Army training activities, any procedure that can meet training requirements more efficiently can have a substantial impact on training cost.

Training designers can enhance training efficiency by appropriate application of training conditions, content, methods, and standards. In determining the training conditions, the designer can assign the training setting, and the kinds and sequencing of training equipment, among other items. Determining training content requires the training designer to decide what skills and tasks should be the focus of training. The training method can affect both the effectiveness and efficiency of training. Finally, training standards can affect retention as well as acquisition.

Effective training design requires a thorough analysis of job functions and activities. At least two kinds of analyses are required. The first describes the job from a functional viewpoint, specifying the missions, functions, and tasks that must be performed by the competent job incumbent. The second determines the specific cognitive, perceptual, and motor activities that need to be carried out to satisfy mission requirements. The analysis of activities specifies the general abilities and specific skills that are required for successful mission performance.

Tasks tell the training designer what must be done to satisfy the mission of the job being trained. Tasks specify the requirements for training by describing what the skilled operator or maintainer must be able to accomplish with his or her activities. Thus, the performance standards for training may be derived from task definitions. Task definitions provide the contingencies for measuring performance, because they explicitly link the outcome of an activity to mission performance.

Skills describe the specific activities required to perform tasks. By examining the general categories of skills required to accomplish a task, the training designer can get a better understanding of the perceptual, cognitive, or motor processes involved in the task. This understanding can provide training methods that specifically address the training needs of these processes. The training designer may also use information about skills to identify the specific operations that are required for competent performance. Because skills describe the specific processes required to accomplish a task, they are central in the definition of the content of training.

Task Training and Skill Training

The term skill refers to general, learned abilities that can be adapted to a particular job by being combined with job-specific knowledge. For our purposes, the critical attributes of general abilities are that they can be adapted to any given domain, they can be sharpened with practice, and they characteristically distinguish expert from novice behavior. Job skills, those identified with a particular domain, are viewed as specific instances of general abilities applied in conjunction with domain-specific knowledge. Skills are distinguished from tasks in that a skill is an ability to perform some aspect of one or more tasks, skills may be applied to several tasks, and skills are concerned with processing activities while tasks are concerned with goals and functions.

The most straightforward approach to training is to train the task requirements directly. This method of training provides soldiers practice on tasks in an environment that is as similar to actual wartime as possible. Training using this approach typically involves the use of real equipment or high-fidelity simulators and realistic training conditions. The major advantage of this approach to training design is that is almost guarantees that training will be relevant to the requirements (since the requirements are being trained directly). Similarly, it is an easy matter to determine training requirements, since they are derived directly from task performance standards.

However, the nature of the tasks and the skills required to perform them may interact to reduce the effectiveness of task training. Under certain conditions, some of the following disadvantages of task training may occur.

1. Feedback may be inappropriate. In the job environment, the link between correct performance and mission outcome may be quite complex, and proper actions may not always produce the best outcome. For example, the proper action may lead to a bad outcome because: (a) there may not have been any chance of obtaining a good outcome, (b) there may have been some error in a subsequent action, or (c) unforseen or random events may have produced the outcome.

2. Feedback may be delayed. Feedback is often delayed in tasks that involve planning. For example, when an air traffic controller directs aircraft to certain heading, it takes time for the aircraft to execute the turn. The controller doesn't know if he has given the correct directions until after the turn has been completed.

3. Feedback may be absent. For example, an air traffic controller may incorrectly determine that there is conflict between two aircraft, when there is actually no conflict. If his directions to the aircraft to avoid the perceived conflict do not actually place them in conflict later on, there will be no feedback that the controller's assessment of the situation was incorrect.

4. The cost may be excessive. Training tasks may involve expensive training equipment, ranges, ammunition, or simulation of opposing forces to provide a context in which an entire task may be performed.

5. Practice may not be sufficient. Because of the delays that are inherent in task performance, or because of the high training cost, it may not be possible to provide the amount of practice required for proficiency.

6. The mental or physical workload involved in performing the task may be so extreme as to inhibit learning.

Some of the problems described above may be solved by changing the training conditions without affecting the tasks that are trained. Changes in training conditions might decrease the realism of the training environment to make training more affordable, enhance feedback, or increase the efficiency of training. Thus, we may train job tasks in a trainer that represents the environment with low fidelity. Similarly, we may speed up or slow down simulated time, enhance cues or performance feedback, or train in conditions that are substantially simpler than actual battlefield conditions. All of these options change the conditions of training, making them different from job performance conditions so that training might be more efficient.

Another approach to the problems changes the content of training by focusing training on the skills that must be learned. Skill training has the capability to compress the time required to train critical activities, to avoid duplication of training when several tasks have common skills, and to reduce the effect of extreme workload by training task components. Using a skill-based training strategy, it may be possible to isolate critical skills, and to provide substantially more training on these skills than would be possible if the skills were embedded in a task. The critical skills acquired may improve the performance of many tasks, so that the need for subsequent task training is reduced. Furthermore, training on very difficult tasks may be easier when the trainee already possesses some of the critical prerequisite skills. Finally, skill-training strategies may require a less realistic representation of the job environment than task-training. We expect that, under the proper circumstances, the use of skill-training methods can improve training cost effectiveness.

However, skill training also has its disadvantages, which we expect would outweigh the advantages in some circumstances. First, learning the individual skills is usually not sufficient for proficient task performance. It is still necessary to provide mission training to coordinate the skills properly. Second, skill training in a context that is sufficiently different from the real battlefield may not transfer to task performance. Thus, we need to compare the conditions of skill training to actual job performance conditions to ensure transfer of training to the job environment.

Design of Skill-Based Training Systems

The previous discussion indicates that a critical aspect of designing a training system that incorporates skill training is determining which skills should be trained. Other problems involve designing skill-based training devices and determining the optimal use of these devices. Also, the combined use of skill-based and task-based training devices in an overall training system must be determined. Methods for training-system design should incorporate these considerations in designing the skill-based component of the training system.

Although current methods for medium selection, training-device design, and training-device evaluation often consider the specific skills that must be trained in order to meet training requirements, existing models for training-device design are focused at the task level. For example, the OSBATS (Optimization of Simulation-Based Training Systems; Sticha, Blacksten, Buede, Singer, Gilligan, Mumaw, & Morrison, 1988) model is principally concerned with determining the task-training conditions, and does not consider changes in training content. The training strategies addressed by the OSBATS model assign task training to different training conditions represented by different training devices. The model views each training activity as relating to a single task or training requirement.

In a task-based analysis, all training resources are assigned to tasks. Training that is of general relevance to the job, but which is not relevant for a

specific task, such as classroom training that provides introductory information, is not considered by task-based models. In the OSBATS model, each task has an established performance requirement that must be satisfied by the training system. The tasks require certain cues and response options in order to reach that performance level. The required cues and response options are used by OSBATS to predict how effective training devices of different levels of fidelity will be in training the tasks. Training-device design options are initially screened according to how many task cue and response requirements can be met using the design. Ultimately, the design options are evaluated by OSBATS according to which options can be used to meet all training requirements at the minimum cost.

The design logic for skill-based training devices differs from that for task-based simulators, but shares some of the same principles. The logic depends on the analysis of the material to be trained into components. Critical components are the underlying general abilities, specific skills, prior learning specific to the situation, and sequencing of the instructional content. A model is required to identify these skill-training requirements, to design a device to train the skills at minimum cost, and to determine the optimal allocation of training among skill-based and task-based training devices through cost and benefit tradeoffs.

Organization of the Report

The terms "skill" and "task" have received several different definitions in the research literature. The next section of the report clarifies our understanding of these terms and their implications for training design. It discusses how skills are defined, how they are distinguished from tasks, what types of skills there are, and how they are identified. This section also briefly reviews some of the research on the effectiveness of skill training.

The third section introduces a cost-effectiveness framework for evaluating skill training, and applies this framework to illustrate the rationale behind skill-training strategies as well as the conditions under which these strategies should be effective. We distinguish three ways that skill training can be used to improve training cost-effectiveness. First, skill-based training can be used to isolate critical skills which are not sufficiently exercised in the task context. The proper skill training strategy can allow the student far more practice applying these skills than would be possible in the context of the task. Second, skill-based training can provide the student with the general competencies that can be applied to many job tasks. Third, skill training can provide the component competencies that are required to perform very complex tasks. This kind of initial skill training can reduce the workload required to learn the tasks, and consequently increase the learning rate.

The fourth section describes our model for the design of skill-based training systems in the context of an example from air traffic control training. This example illustrates the four major design processes covered in the model. These processes identify skills that require training, develop skill-training strategies,

design training devices to implement the skill-training strategies, and allocate training resources to the skill training.

The fifth section contains a formal system description of the model for skill-based training design. The description includes a hierarchical representation of the major model activities, and a description of the information required for its use.

The final section provides a discussion of modeling issues that could affect the formal model developed. User issues are raised that affect implementing a decision aid of this sort. The section presents a discussion of research issues, and the need for both research and further development in this area.

SKILL DEFINITION AND CHARACTERIZATION

In this section, we provide a foundation for our model of skill-based training optimization by describing the notion of "skill" as a training construct, and by outlining a method for identifying skills within a job domain. We begin with a brief review of the history of skill training. In it, we discuss briefly some of the more recent empirical findings related to skill training. We then discuss the strengths and weaknesses of the definitions of "task" and "skill" as currently applied to military training, and propose revisions to them. Finally, we discuss the kinds of skills that are considered in the model, and briefly outline an approach to identify skills for training.

Research on Skill Training

The history of research related to skill acquisition is long and rich. For example, Adams' (1987) review of motor skill research goes back nearly a century for its earliest references. Despite the diversity of the literature and the nearly universal lack of consensus on a single definition of "skill," there is much that is consistent. In this brief review, we will consider several descriptions of skills and skilled behavior. We will also review several methods for training skills. Our goal is to provide a rationale for the definition of skill that we have developed to guide the development of our skill-based training optimization model.

What is a Skill?

Adams (1987) suggests that the roots of our understanding of skill go back to work by the British psychologist, Pear, in 1927. "Pear said that skill has an explicit reference to the quantity and quality of output. A skill is learned, and it is distinguished from capacity and ability because an individual may have the capacity and ability to perform a skill but cannot do it because it has not been learned" (p. 42). Summarizing Pear's early contributions and the continued refinement since his time, Adams identified three characteristics that define skills (p. 42):

1. Skill is a wide behavioral domain. From the beginning, skill has meant a wide variety of behaviors to analysts, and the behaviors have almost always been complex.

2. Skill is learned. Welford (1968, pp. 12-13) said that "skill is acquired after long training, and consists of competent, expert, rapid and accurate performance."

3. Any behavior that has been called skilled involves combinations of cognitive, perceptual, and motor processes with different weights. Mathematicians have cognition heavily weighted in the description of their behavior, with virtually no

> weight for perception or the motor response with which they write the answer to a problem. On the other hand, the behavior of tennis players could not be meaningfully described without including the motor responses stemming from their perceptual evaluation of the situation and the cognition in their decision making.

<u>Distinguishing skills and related concepts</u>. Fleishman (1966) draws a distinction between abilities and skills. He uses "ability" to refer to comparatively general and long lasting traits. Although "abilities" are enduring and difficult to change, they are learned. They develop at different rates and most of the learning occurs during childhood and adolescence.

Skill refers to the level of proficiency an individual exhibits relative to a particular task or group of related tasks.

> Thus, when we speak of acquiring the skill of operating a turret lathe, we mean that this person has acquired the sequence of responses required by this specific task. The assumption is that the skills involved in complex activities can be described in terms of the more basic abilities. For example, the level of performance a person can attain on a turret lathe may depend on his basic abilities of manual dexterity and motor coordination. However, these same basic abilities may be important to proficiency in other skills as well (p. 148).

Fleishman's more recent work (eg. Fleishman, 1982; Mallamad, Levine, & Fleishman, 1980) has been on the development of taxonomies of abilities and skills. He has developed a list of 40 abilities which can be used to describe skilled performance on tasks. His taxonomic work has resulted in very reliable methods for identifying the abilities underlying the potential level of skill which can be attained for the tasks of interest.

While Fleishman has focused on the relationship between abilities and skilled performance on tasks, Gagné (1975) is more interested in the outcomes of learning.

> Learning establishes persisting states in the learner. These states make possible the performances that are observed. Although the performances themselves vary in many dimensions, the underlying states may be classified as having certain formal properties in common. We choose here to call these persisting states "capabilities," a word which implies that they make the individual "capable" of certain performances ... In addition, there is the word "capacity," which traditionally has a different meaning, namely, the innate limit of what an individual can learn. According to this usage, an

individual may have the "capacity" for learning certain "capabilities;" but what he learns are the "capabilities" (p. 50).

Gagné does not provide a list of human "capacities." However, he does classify "capabilities." At the highest level, there are five categories of learned capabilities: Verbal Information, Intellectual Skill, Cognitive Strategy, Attitude, and Motor Skill. The Intellectual Skill category is subdivided. The most important subcategories for practical purposes are: Discrimination, Concrete Concept, Defined Concept, Rule, Higher-Order Rule. Any learning task may be classified according to Gagné's categories. Ideal conditions for learning and recommendations for teaching strategies vary from category to category. Hence, Gagné provides a framework for designing instruction that should facilitate learning within each category in an optimal manner.

Recent research in cognitive psychology takes a somewhat different view of skill, skill acquisition, and skilled behavior. Card, Moran, and Newell (1983) view "skilled behavior" as one anchor point on a continuum which is anchored by problem solving at the other extreme. In other words, one cannot talk of "a" skill. Rather, as one learns to negotiate the problem space underlying a task, one begins to exhibit skilled behavior. They state:

> Unfortunately, there is no basis for constructing a general taxonomy of cognitive skills. Cognitive skills exist for all cognitive tasks (ie. all situations that permit problem solving), provided that practice on them is possible. The taxonomy of all cognitive skills is an image of the taxonomy of all possible tasks (p. 396).

Stages of skill acquisition. While it may be true that each cognitive task requires a unique cognitive skill for expertise to be demonstrated, Anderson (1985) argues that individuals also possess general problem solving procedures in order to develop skills in novel domains. Anderson proposes that skill development occurs in three stages. The first stage is called the cognitive stage, the second stage is the associative stage, and the final stage is the autonomous stage.

During Anderson's first stage, learners commit to memory a set of facts relevant to the skill. These facts are called declarative knowledge. Learners use domain-general problem solving procedures and declarative knowledge to guide their problem solving. The most common domain-general problem-solving procedures are heuristics. Anderson includes difference-reduction methods, means-end analysis, working backward, and analogical reasoning as examples of such domain-general heuristics. Analogical reasoning "attempts to use the structure of the solution to one problem to guide solutions to another problem" (p. 218). The other three methods are all variations of a strategy that attempts to define subgoals that must be achieved in order to achieve the goal of solving a given problem.

During the associative stage two important phenomena occur. First, errors are detected and eliminated. Second, connections among the various elements necessary for performance are strengthened and smoothed. This process involves the transformation of declarative knowledge into procedural knowledge. By the end of the associative stage, domain-specific procedures are available so that the learner is not dependent on the much slower combination of declarative knowledge and domain-general problem-solving procedures.

In the autonomous stage of skill acquisition, the skill becomes more automated and rapid. According to Anderson:

> No sharp distinction exists between the autonomous and associative stage. The autonomous might be considered an extension of the associative stage. Because facility in the skill increases, verbal mediation in the performance of the task often disappears at this point. In fact, the ability to verbalize knowledge of the skill can be lost altogether. This autonomous stage appears to extend indefinitely. Throughout it, the skill gradually improves (p. 235).

Anderson's work suggests that a rich store of domain-general problem-solving procedures would facilitate problem solving and skill acquisition in novel fields. New declarative knowledge, combined with the appropriate choice of domain-general procedures, should lead to the development of domain-specific procedures. Automatic domain-specific procedures should produce skilled behavior.

Recent work by Perkins and Salomon (1989) is supportive of the view that both domain-general procedures and knowledge of the domain are necessary for skill acquisition. Perkins and Salomon view general cognitive skills as "devices for retrieving and wielding domain-specific knowledge" (p. 23). These general cognitive skills exist, <u>and</u> they always function in contextualized ways.

Perkins and Salomon do not have a list of cognitive skills. However, they do describe the characteristics of cognitive skills and provide examples. A cognitive skill is expected to exhibit the following characteristics: (a) the skill shows seeming use, that is, experts use the skill; (b) the skill appears to play an important role in task reasoning; (c) the skill is demonstrably transferrable and is used in a wide variety of tasks; and (d) the skill is commonly absent in novices. Examples of skills include looking for counterexamples, using analogies and searching for misanalogies, referring to intuitive mental models, testing extreme cases of potential solutions, and constructing simpler problems that are similar to the problem of interest.

Studies of Skill-based Training

A growing body of research has shown skill training in various forms and across several applications, to be a viable instructional approach. It can focus

attention on procedures and associated skills that, while important to overall performance, are not captured in task-based training. It can foster the development and automation of skills more efficiently than in task-based training. It can also reduce costs by demanding lower levels of physical fidelity in the instructional situation, and by combining training on several skills in a single program. In skill-training environments, for example, instructional situations or scenarios need not correspond to job tasks to provide valuable learning opportunities. Scenarios can be tailored to render maximal instructional value, while avoiding the high cost of adhering to many job-specific constraints (e.g., physical and functional fidelity of the job environment). Finally, skill-based training can facilitate transfer of knowledge by exposing the learner to the utility of a skill in various contexts.

Part-task training research. Much of the research on skill training has been conducted under the heading of part-task training (PTT). (For a detailed review of the PTT literature, see Knerr, Morrison, Mumaw, Stein, Sticha, Hoffman, Buede, & Holding, 1986.) The PTT approach seeks to divide instruction on complex jobs into manageable parts, and can be more effective and less costly than instruction in a whole-task format. One obstacle to the application of PTT, however, is how to divide up the job to achieve these benefits. Naylor (1962) proposes three methods for dividing job tasks for training: simplification, segmentation, and fractionation.

The simplification technique adjusts one or more characteristics of a task to reduce task difficulty. As learning progresses, difficulty is systematically increased to more closely approximate actual task parameters. Segmentation partitions tasks into independent sub-tasks along temporal or spatial dimensions. Sub-tasks are learned separately and then recombined to form the whole task. Both of these methods suggest a task-based approach to training.

The third method, fractionation, is more appropriate for skill-based training. The fractionation technique divides tasks into task components that are performed simultaneously on the job. Each fraction represents a psycho-motor, perceptual, or cognitive competency, or skill, that the learner must possess to perform the whole task proficiently. Once identified, fractions are trained separately before being combined in whole-task training.

The idea of practicing skills in isolation from others is consistent with several learning models. Gagné (1968) introduced the notion of learning hierarchies of intellectual skills. In determining how to sequence instruction, capabilities that the learner must have to perform the task are identified and sequenced according the order in which they become relevant in performing the task. The idea is that certain capabilities are prerequisites for others and therefore must be acquired before others can be learned. Fitts' (1964) work on complex skill acquisition divides learning into three stages: cognitive, associative, and autonomous. The basis of a skill is formed in the first stage through conscious mediation. The second stage establishes and refines the skill through

practice until conscious attention is no longer required. The third stage is characterized by increasing speed and accuracy in applying the skill. While Fitts' model does not address the issue of training directly, the idea of practicing individual task components to autonomy has implications for the effectiveness of skill-based training. The role of fractionation as an instructional technique can be more clearly seen in recent extensions to Fitts' model. Anderson, Conrad, and Corbett (1989) found that LISP programming skills can be divided into units (production rules) that are learned independently of one another. Presenting the learner with problems selected to practice weak skills was shown to improve learning. Schneider (1985), in his work on training perceptual skills emphasizes the importance of teaching component skills in isolation and then gradually combining them to approximate whole-task performance. (A more detailed description of Schneider's work is presented below.)

Based on this work, the military has implemented procedural, cognitive, and perceptual pre-training courses to help students develop basic skills (Knerr, et al., 1986). Procedural skill training is very inexpensive and is effective for training and sustaining skills that receive little practice on the job and are, therefore, susceptible to forgetting (Adams, 1960). Cognitive pre-training focuses on knowledge of the domain that is thought to be required for actual task performance. While it has not shown effects as dramatic as the other two forms of pre-training, it has been shown to facilitate initial performance in job task training (Smith, Waters, & Edwards, 1975). Perceptual pre-training, the most widely studied of the three, focuses on prerequisite skills, such as recognizing patterns or cues, that must become automated to allow for time-sharing with more demanding skills. Training in perceptual component skills has been demonstrated to be very effective in aviation-related jobs (Schneider, Vidulich, & Yeh, 1982; Schneider, 1985; Myers & Fisk, 1987; Fisk & Eggemier, 1988).

Schneider and his colleagues have identified and trained skills important to the job of air intercept control (AIC). AIC can be broken down into two main classes of tasks: (a) collecting data about the current situation, and (b) transmitting those data to aircraft and ship weapons controllers (Halley, Hooks, Lanford, & Nowell, 1981). Two of the skills involved in these tasks are monitoring a radar screen and calculating trajectories. These superordinate skills are not at the appropriate level of specificity for initial training, and must therefore be further divided into component skills.

Schneider (1985) identified the component skills used in performing a particular sub-task of AIC called "co-speed nearest collision intercepts." This task involves eight motor, perceptual, and cognitive skills. For example, "heading identification" involves the use of spatial reasoning skills to quickly identify heading angle to within 10 degrees. "Basic tracking" skill requires fine motor movements to accurately position a cursor over a radar blip twice in succession. All eight of the skills can be initially trained independently, and then combined into an orchestrated superordinate skill, subtask, or whole task performance.

Based on this analysis Schneider has developed a computer-based skill trainer that is currently used to train the AIC job.

The methods used by Schneider (1985) are effective, but are also very resource intensive. Recently, Fisk and his colleagues (Fisk & Eggemeier, 1988; Eggemeier, Fisk, Robbins, & Lawless, 1988) developed a systematic front-end analysis methodology for identifying component skills for PTT. The method uses interview and observation techniques to identify automatic processes that are components of complex skills. It has been used to identify cognitive, perceptual, and motor skills that underlie operator performance in aircraft command-and-control tasks.

Application of computer games. Another skill training paradigm that appears promising is the application of computer games to teaching complex skills. Gopher, Weil, Bareket, & Caspi (1988) designed a computer game to simulate aviation-related tasks involving psychomotor and cognitive skill components. Their goal was to facilitate development of selective attention and resource allocation skills in complex real-time jobs, such as piloting an aircraft, in a low-cost simulation environment. It is important to note that the game was designed to grossly simplify the physical environment of the cockpit (i.e., low physical fidelity), while closely approximating the skill components of the job (i.e., high psychological fidelity). Their approach may be considered PTT in that the game is intended to train certain piloting skills. However, their method deviates from traditional PTT in that the task (the game) is not decomposed into its parts for training. Rather, the task is presented in its entirety, and the training alternatively emphasizes the need to direct attention and allocate resources according to changes in task demands.

The effectiveness of the training was tested experimentally by inserting the game training into a flight training curriculum. Three groups of student pilots received either 10 hours of game practice with skill instruction, 10 hours of game practice without instruction, or no practice between two phases of flight school. Skill transfer was measured by actual performance scores in the latter phase of flight training. Results indicate that subjects who received game practice with instruction scored better in actual flight training than either of the other two groups. Gopher, et al. conclude that a high psychological fidelity, low physical fidelity trainer can be effective for training complex skills within the context of a whole-task training curriculum.

Summary

The examples cited in this brief review cover a wide range in both time and point of view. They use different vocabulary and suggest different levels of detail in addressing domain-specific skilled behavior and domain-general problem solving procedures. However, they agree in the sense that there are general abilities, capacities, or domain-general procedures which are applied to the development of domain-specific skills and skilled behavior. It appears to be valuable to consider

training at both levels; one can learn domain-general procedures and one must learn and practice domain-specific skills. At also appears that skill training is a viable and effective technique for developing proficiency in complex job domains. In designing optimal training from a skills point of view, one must consider the variety of levels, the generality, and the specificity that can be implied by the term "skill." In the next section we propose a working definition of skill and an approach to identifying skills that is derived from this body of research.

Distinguishing Tasks and Skills

In this section, we define the terms "task" and "skill" as a foundation for developing an understanding of the role these constructs play in the specification and development of training systems. The ability to distinguish the two is critical to the development of a skill-based training model that can be used by those other than research psychologists. Our characterization of tasks and skills extends the traditional usage of the terms in light of recent theoretical advances in the study of human information processing.

Tasks

We begin with the definitions of "task" and "skill" contained in MIL-HDBK-220B, Glossary of Training Device Terms (1986): "A task is the lowest level of behavior in a job that describes the performance of a meaningful job function."

This definition reduces performance to a lowest common denominator, the task, at a level unique to the particular job under consideration. For our purposes, the definition is inadequate for two related reasons. First, it seems to equate the function or goal to be accomplished with the procedure employed to accomplish it. Clearly, one can specify a function to be performed without enumerating the steps required to perform it. Conversely, following a sequence of steps need give no indication of its function, when it should be performed, or why. One characteristic of expertise in complex technical domains is the availability of multiple strategies or procedures to accomplish a task, each of which may rely on a different kind of skill. Expert electronics troubleshooters, for example, use different kinds of troubleshooting strategies (e.g., split-half, historical, reconfiguration), which rely on various cognitive, perceptual, and motor skills such as inductive reasoning, pattern recognition, and dexterity (Means & Gott, 1988).

Second, it is unclear whether the same behavior or procedure applied in two different contexts (e.g., job domains) will be identified as a "task" in both contexts. The key phrase in the definition is "meaningful job function." To define "task" it appears that one must first define the term "meaningful job function." At what point does a behavior become meaningful? This question must be answered independently for each job domain under consideration. It is possible that in one domain a procedure is deemed too insignificant in the context of the overall job to be considered a meaningful job function, while the same procedure is considered integral to proficiency in a second domain. Presumably, a task-based approach

would identify the procedure as a candidate for training in the latter domain only. While this is not inherently undesirable, it can inhibit the learner from transferring knowledge from one context to another. Even within a job, the same procedure may apply in two contexts. Due to differences in overall complexity between the two contexts, however, the procedure may only be identified for training in one context, thereby reducing the possibility of transferring that knowledge to the second context.

We view job performance as a process of establishing and satisfying goals. One way to facilitate the identification of tasks in a meaningful way is to define a task in terms of its function, or the goal to be accomplished, rather than the behavior required to execute it. In most cases the job performance problem space contains a hierarchy of goals and subgoals that correspond to tasks and their component activities. This approach separates what has to be done and when to do it from how it gets done. Thus, we propose the following definition of task:

> A task is a job-specific goal that must be satisfied or function that must be accomplished. A task statement describes what must be done, but not how it will be accomplished. Tasks can be sequential or hierarchical in nature and can exist at various levels of specificity within a job domain. A task's position in the hierarchy specifies the conditions under which (when) it applies.

Skills

By separating what and when from how, we allow the skills used in performing tasks to be defined independently from tasks. The MIL-HDBK-220B definition of skill is the following: "A skill is the ability to perform a job-related activity that contributes to the effective performance of a task."

This definition contains two important assumptions. The first assumption is that skill is characterized as an ability possessed by the performer; it is not the actual set of behaviors but rather the competence to bring the appropriate knowledge to bear in executing the behaviors. It is a general competency that can be adapted to a specific domain. This suggests that skill exists in two states, or stages. In the first stage, skill exists independently from any job domain. It is defined in terms of domain-independent attributes of the human information-processing system. These include motor, perceptual, and cognitive attributes. The second stage is the domain-specific competency that results from the combination of domain-independent abilities and domain knowledge. This characterization is similar to Fleishman's (1967) distinction between ability and skill. Given this two-stage definition, it should be possible to look at performance on a specific task and identify the human competencies required to perform that task proficiently in terms of domain-independent abilities and domain knowledge.

The second implicit assumption in the MIL-HDBK-220B definition is that skills are associated with activities, which are components of (and therefore

smaller than) tasks. This characterization corresponds well with the notion of primary, or enabling, skill. However, it artificially restricts skills to a certain size or level of specificity that is dependent on the level at which tasks are defined. This could lead one to the conclusion that skills cannot be treated independently from the tasks through which they are instantiated.

This conclusion would be erroneous for two reasons. First, it suggests that proficient performance acquired outside the context of the job itself may not be useful on the job since it is not tied to a job task. We argue that it is often valuable to consider, and indeed teach, skills in isolation from job tasks. Second, we argue that performance requiring proficiency on a number of related tasks in concert can be considered an instantiation of a single skill. Indeed, the restriction of skill to describe sub-task level behavior introduces the danger of omitting many higher-level (i.e., cognitive) skills from consideration. Our approach identifies skills at several levels of performance. Thus, our definition of skill in a job context is the following:

> Skill is the adaptation of human abilities to a particular job, in conjunction with domain-specific knowledge, resulting in performance that accomplishes a job-related goal.

Identifying Skills

To realize the promise of skill-based training, training developers must be able to identify appropriate skills. In this section, we will outline, in broad terms, an approach to identifying job skills. The specific steps applied in a given situation will vary with each application. For example, there are several points at which the identification of skills can be initiated. One could begin with a thorough understanding of domain-independent abilities and little knowledge of the job domain (as a psychologist would) or vice versa (from a subject-matter expert point of view). On a second dimension, one could begin by looking at the job as a whole or at individual tasks. We provide an example of one application in a later section. That example assumes that a set of tasks has been specified (through task analysis), and that a subject-matter expert will be employed to identify and select a set of skills as candidates for skill-based training.

Our approach to identifying skills focuses on three categories of human competence commonly found in task and skill taxonomies: psychomotor, perceptual, and cognitive (see review of literature in Fleishman & Quaintance, 1984). Other categories, such as physical and social competence, have been excluded from consideration in the present context. Within each category our approach posits "general purpose" information-processing abilities (Fleishman, 1967). A tentative list general abilities for each category is shown in Table 1. The list was compiled from several sources, including Miller's (1971) systems task vocabulary, Fleishman & Quaintance's (1984) ability categories, and Gagné's (1974) categories of learning outcomes. Definitions of the abilities are provided in the Appendix. The critical attributes of abilities for our purposes are that

Table 1
List of General Abilities

Psychomotor Abilities	
Control precision	Reaction speed
Dexterity	Aiming
Multilimb coordination	Response orientation
Rate control	
Perceptual Abilities	
Detection	Pattern recognition
Selective attention	Visualization
Spatial reasoning	Discrimination
Cognitive Abilities	
Verbal comprehension	Abstraction
Quantitative reasoning	Computation
Meta-cognition	Time sharing
Inductive reasoning	Deductive reasoning
Analogical reasoning	Planning
Prioritizing	Knowledge compilation
Information recall	Forward chaining
Backward chaining	Categorization

they can be sharpened with practice, and they provide dimensions that can be used to discriminate expert from novice behavior.

Job Skills

Job skills, identified within a particular domain (via task analysis), are viewed as instantiations of abilities applied in conjunction with domain-specific knowledge. The knowledge component of a job skill is often necessary for the identification of the underlying ability. For example, in air traffic control, speed estimation can be accomplished several ways, including computation, spatial reasoning, and pattern recognition. Specific knowledge of the job environment and the objects in that environment will dictate which of these abilities will be used in a given situation.

We do not offer a job skill taxonomy because to do so would add an artificial layer to our analysis between abilities and domain knowledge. Such a list would, by necessity, be at a level that spanned many jobs, but would be difficult to use for

skill training purposes in any one job. We believe it is more useful to work directly from a task and skills analysis to identify job skills and their underlying abilities.

Skilled Performance

Skilled performance is the observable manifestation of the application and refinement of abilities in a specific task environment. Hence, one determinant of skilled performance, or expertise, is the amount and kind of domain-specific knowledge the performer can call upon in a given situation. Abilities cannot be applied effectively in a complex domain without the knowledge to drive them. We distinguish among three types of domain-specific knowledge: factual, procedural, and strategic. Factual knowledge is information about concepts, rules, and objects in the job environment, including their attributes and states. Examples are the rules of use between two airspace sectors set out in a letter of agreement or the performance characteristics of a DC-10 aircraft. Procedural knowledge is knowing how to do something. The steps involved in managing a holding pattern stack is one example. Strategic knowledge consists of domain-specific goals, models, and strategies that mediate performance, especially in non-routine situations in which no simple procedure applies. An example of strategic knowledge is a plan for sequencing aircraft arrivals into an airport.

Early in skill acquisition, knowledge is applied in an inefficient, effortful fashion through a process that Anderson (1983) has named "interpretive" processing. Even simple procedures are, at first, performed by following a discrete set of declarative instructions. Over time, through repeated application, declarative knowledge is built up, or compiled, into unitary procedures until their application requires little or no conscious attention. We can think of these units at productions, or if-then rules, that contain information from each of the three knowledge categories. That is, a production would contain a goal to be accomplished, the conditions under which it applies, and an action to be executed. When compiled, knowledge is applied in an efficient, all-or-none fashion when called for, and is typically not subject to errors. Knowledge compilation allows a technician, for example, to perform a diagnostic procedure without having to think about (or look up) all the steps involved. It is the application of knowledge in this compiled state that we generally characterize as skilled performance.

By defining skill as the adaptation of human competencies to a particular job, we have eliminated the restrictions placed on the level at which skills can be identified by the specification of tasks. We can now speak of component skills, associated with the activity (or sub-task) level of performance, and superordinate skills at the task and function levels. The confusion between skills and procedures, and between skills and tasks is also alleviated. Since a particular skill is defined in terms of: (a) the set of competencies used by the performer in conjunction with (b) domain-specific knowledge to execute (c) a procedure that accomplishes (d) a goal, skill cannot simply be equated with tasks or procedures.

A detailed example of the process of identifying candidate skills is presented in fourth section of the report. What follows is only a brief outline. First candidate skills must be identified, which involves a hierarchical decomposition of tasks into successive layers of sub-tasks and associated job skills until a "trainable" job skill is identified. By trainable we mean that the skill can be defined in terms of the domain-independent abilities and domain-specific knowledge required in performance, as defined above. In the language of Instructional Systems Development (ISD), one must be able to specify a clear learning objective and precise performance criteria. In cognitive theoretic terms, one must be able to specify the extent knowledge, input information, information processing mechanisms or processes, and output behavior. Skills expressed at a level from which training objectives cannot be derived must be decomposed into their component skills. For example, air traffic controllers will tell you that the ability to "see the traffic" is the most important skill a controller must have. However, they are unable to specify how they do it, and more importantly, how to train students to "see" traffic. By breaking that superordinate skill down further, however, we find several perceptual and cognitive component skills that can be trained. These skills, then, become candidates for skill-based training.

Second, after identifying the component skills, the instructional developer must determine whether they are appropriate for skill training. The appropriate candidate skill should display the following characteristics: (a) it should be critical to accomplishing the task(s), (b) it should require a significant amount of effort to acquire, (c) it should be applied consistently across situations within the domain, and (d) it should be trainable outside the context of actual job tasks. In addition, two entry conditions should exist for appropriate skills. Acquisition of the skill should not require significant amounts of prerequisite knowledge to train, and should not be dependent upon training two or more functions concurrently (time-sharing).

Summary

The approach we have outlined and the principles it embodies are described in greater detail in the example problem and formal model description. It is important to emphasize that we do not propose that skill-based training supplant task-based training. We view the two as complementary components of an overall training system. Task-based training provides the learner with an understanding of the job environment, the context in which performance takes place. Job-specific concepts (e.g., functional and structural relationships) and strategies (what to do, when, and why) are developed from exposure to job tasks. Skill-based training allows the learner to progress more efficiently through task training by isolating and providing practice on individual component or superordinate skills. In jobs that involve real-time performance, such as air traffic control, skill-based training can sharpen skills (from keyboard entry to prioritization and planning). In off-line jobs such as electronics troubleshooting, learning to use an oscilloscope or to read diagnostic software code might also be candidates for skill-based training. These

skills must be applied effortlessly before the learner can effectively orchestrate conceptual and strategic knowledge into a complete, proficient performance.

The next section presents another way of looking at the benefits of skill-based training, focusing on cost-effectiveness rather than psychological arguments. It is important to note that, while coming from divergent perspectives, the conclusions drawn from the two viewpoints are consistent with respect to the feasibility of the skill-based approach.

RATIONALE FOR SKILL-BASED TRAINING

In this section, we describe three ways that skill-based training could improve training effectiveness: (a) Skill-based training could be used to isolate critical skills to provide more training on these skills in a given amount of time than could be provided if the skills were trained in the context of the task. (b) Skill-based training could be used to train skills that are components of many tasks required for successful mission performance. (c) Skill-based training could be used to reduce attentional demands at early stages of training of complex tasks. The effects of these three factors on training cost-effectiveness is enhanced if training the skill in isolation can be accomplished using a cheaper training device than would be required to train the task in which the skill is used.

The remainder of this section illustrates how these benefits of skill-based training could occur using a simple mathematical framework based on learning curves. The general framework also provides a way to discuss the costs and benefits of different training strategies. The framework is developed in the first subsection, and then applied to illustrate the costs and benefits of skill-based training strategies.

Framework for Analyzing Skill-Based Training Cost-Effectiveness

The goal of the learning framework is to represent how well and how quickly training requirements can be attained as a result of various training activities. The training requirements are typically represented as task performance standards in the context of a mission scenario. Training activities can include training on actual equipment, in a classroom, or using a training device, simulator, or other training medium. In addition, the training activities may train the tasks directly or may be focused on the underlying skills required for successful mission performance. Our learning framework uses a learning curve to describe the improvements in task performance that result from a single type of training activity. Cost-effective training activities may be chosen by comparing the learning curves for different training activities for a given training requirement.

Skill-based training strategies may be represented by three components, as illustrated in Figure 1. These three components involve (a) original skill learning, (b) transfer of training to the tested task on operational equipment, and (c) task training to meet the training requirements on operational equipment. The example shown in Figure 1 illustrates the effects of approximately 10 hours of skill-based training. The skill-based training produces fairly high skill performance, but because the skill is only one component of the task, performance transfers imperfectly to the task. However, the skill training replaces approximately 2.5 hours of training on the task. Therefore, if the hourly skill training cost is less than 25% of the cost of task training, it would be more efficient than task training.

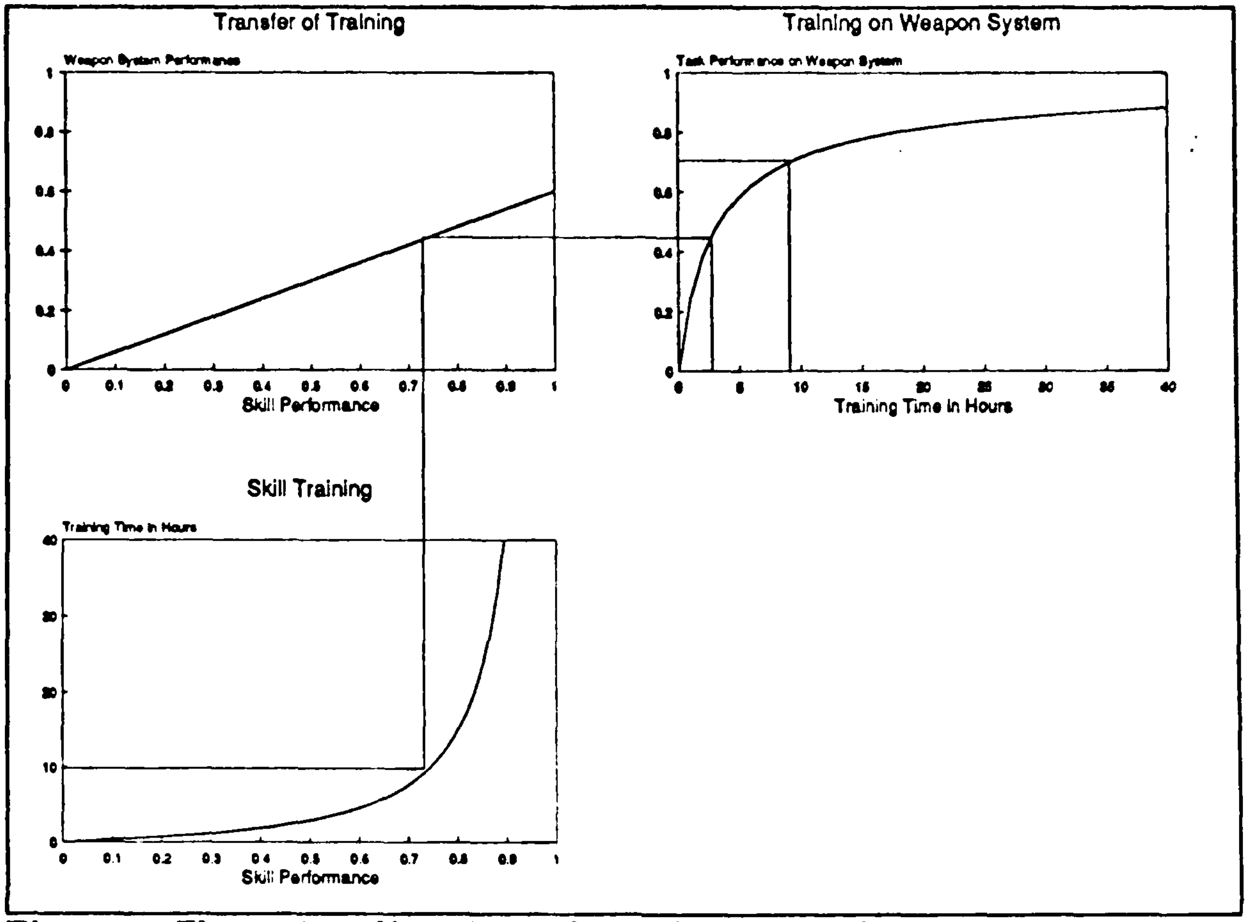


Figure 1. Illustration of learning and transfer framework.

The central elements of the framework are the general functional form of the learning curve, the characterization of transfer of training, and effects of attentional capacities on the learning rate. From these three factors, we may determine the slope of the learning curve, and calculate cost-effective skill-based training strategies. A critical assumption of this simple framework is that the shape of the task learning curve is not affected by either the amount or pattern of prior skill training. That is, the effect of prior skill training on task learning must be summarized by the task performance level produced by the skill training. Problems would arise in determining the cost tradeoffs if the learning curve for the task was distorted by the acquisition of the skill.

Functional Form of the Learning Curve

For many activities, a power function provides a good account of the relationship between performance time and amount of practice (Newell & Rosenbloom, 1981; Boff & Lincoln, 1988). The power function also describes skill acquisition when performance is assessed by other measures, such as errors (Newell & Rosenbloom, 1981). The following equation shows the most general form of the power law of practice.

$$P(t) = A + C(S + t)^{-k}, \quad (1)$$

where A is the asymptotic performance level as the amount of practice (t) increases without limit, S is the amount of training equivalent to prior experience, and C and k are learning rate parameters. P is a monotonically decreasing function of its argument, t. At low levels of t, performance improvements (as measured by decreases in performance time or errors) occur at a relatively high rate; as the amount of practice (t) increases, the rate of improvement decreases.

When we consider measures of performance that increase with practice, we need to reverse the direction of the power function. That is, the performance must increase with practice, rather than decrease with practice. If we map the range of possible performance levels to the interval [0,1], then we may represent the power law of practice with the following equation:

$$P(t) = 1 - [1 + C(S + t)]^{-k}. \quad (2)$$

The functions shown in Figure 1 illustrate the shape of the resulting power function.

Transfer of Training

Since possessing a specific skill is just one component of competent task performance, we would expect skill training to transfer imperfectly to task performance. Figure 1 expresses transfer of training as a linear function, consistent with Cronholm (1985). The degree of transfer of training is represented by the slope of the function. Because we represent transfer of training as a linear function, we may easily combine the learning and transfer functions to obtain the following composite function that expresses task performance as a function of skill training:

$$P(t) = A\{1 - [1 + C(S + t)]^{-k}\}. \quad (3)$$

The asymptote of this function, A, is the slope of the transfer of training function. We expect that the asymptote will depend on how critical the skill is in determining task performance. Training on very critical skills will produce a composite learning-transfer function with an asymptote near 1.0; training on less critical skills will produce a function with a lower asymptote. The composite learning-transfer functions that correspond to the functions shown in the previous example are shown in Figure 2. S and k are set to 0.0 and 0.7, respectively, for both curves. For the task training curve, C = 0.5, and A = 1.0. For the skill training curve, C = 0.6, and A = 0.6.

Learning Rate

The learning rate of the power function depends on two parameters of the function, C and k. Card, Moran, and Newell (1983) have suggested that the

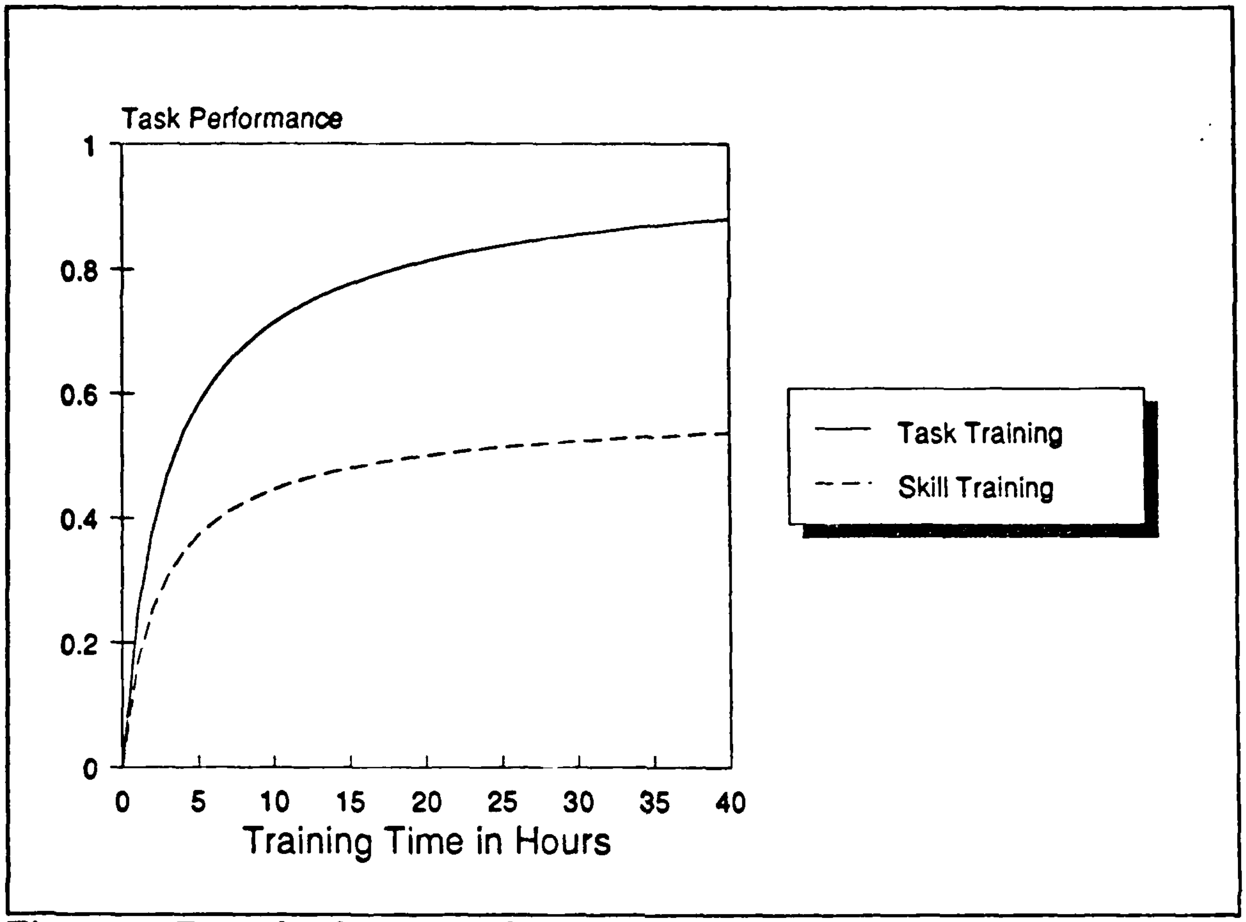


Figure 2. Example of composite learning and transfer functions.

exponent is relatively constant; we will assume that k = 0.7 for this discussion. Thus, in the application of these functions, changes in the learning rate are represented by changes in C. Changes in the learning rate may reflect training strategies that make training more or less efficient. For example, a skill-based training strategy may allow more training trials to occur in a given amount of time, leading to a higher value of C. In addition, the use of appropriate instructional features may make training trials more effective, again increasing the value of C.

A more complicated change in the learning function may occur when very difficult tasks are being trained. This change will occur if the degree of difficulty exceeds the learning capacity of the student. In other words, when a task is very difficult it may require more attentional capacity than is possessed by the student. Thus early learning may be slower than would be indicated by the baseline power function. However, as performance on the task improves, it begins to require less attention. At some point the attentional requirements of the task are within the capabilities of the student, and learning proceeds at its nominal rate.

This simple representation of the role of attentional capacity in learning does not distinguish the cause of the learning difficulty. At least three causes are

plausible: (a) workload may be high because of the need to perform several task elements simultaneously; (b) task-element performance may interfere with rehearsal processes, or (c) sequential links between task elements may prevent successful performance of later task elements without the cues provided by completion of earlier task elements. Knowledge of the cause of high attentional demands may affect the choice of skills for training or the design of training devices for skill training. However, the immediate purpose of this discussion is to provide a tentative description of the effects of attentional limitations on learning, rather than to determine their causes. Furthermore, determining the causes of attentional demands will require considerable additional research. Hence, we will not distinguish these three possible causes in the following discussion.

Our formal treatment of the effects of attention limits is similar to that of Knerr, Morrison, Mumaw, Sticha, Blacksten, Harris, and Lahey (1987). We begin by examining the derivative of Equation 2 (to simplify the presentation, we assume that the asymptote of the learning function is 1.0),

$$P'(t) = kC[1 + C(S + t)]^{-(k+1)}. \tag{4}$$

Algebraic manipulation of Equation 2 allows us to determine that $[1 + C(S + t)]$ is equal to $(1 - P)^{-1/k}$. Hence, we may rewrite Equation 4 as follows:

$$P'(t) = kC(1 - P)^{(k+1)/k}. \tag{5}$$

Equation 5 represents the slope of the learning function, $P'(t)$, as a function of the performance level, P.

In the following development, we define a learning function, $Q(t)$, with a derivative that is the same as $P'(t)$ when the attention requirements of the task are within the capabilities of the student, but that has a derivative that is less than $P'(t)$ when the task requires capabilities greater than those possessed by the student. We will denote the task attention requirement by R, and the student attention limit by L. Then we will define $Q(t)$ as a function such that

$$Q'(t) = kCf(1 - Q)^{(k+1)/k}, \tag{6}$$

where

$$f = \begin{cases} L/[R(1 - Q)] & \text{if } Q < 1 - L/R \\ 1 & \text{otherwise.} \end{cases}$$

The function, f, is always less than 1.0. Assuming that $L < R$, f has the value L/R when $Q = 0.0$. As performance (Q) improves, f increases correspondingly, as does the learning rate (since f is a multiplicative factor of Q'). When Q increases further to $1 - L/R$, then $f = 1$, and the Q has the same slope as P. As Q increases further, the value of f remains 1.

We will only be concerned with the first case, ($Q < 1 - L/R$). By combining the definition of f into Equation 6, we obtain the following equation.

$$Q'(t) = (kCL/R)(1 - Q)^{1/k}. \tag{7}$$

Equation 7 is a first order differential equation in which the variables can be separated. This equation can be solved for Q to yield:

$$Q(t) = 1 - \{1 + [(1 - k)LC/R](t + S)\}^{k/(k-1)}. \tag{8}$$

Equation 8 shows that Q(t) is a power function of the same form as P(t) (Equation 2), but with different learning rate. Figure 3 compares the two functions, assuming that the attention requirement is three times greater than the student's capability (i.e., $R = 3$, $L = 1$). Other parameters have the same values as the task learning curve shown in Figure 2 (i.e., $C = 0.5$, $k = 0.7$, $A = 1.0$). Under this condition, training is considerably slower than what would be the case if there were effects of attention capacity. It takes 12 hours to accomplish the training that would have required about 7.5 hours if there were no attention effects.

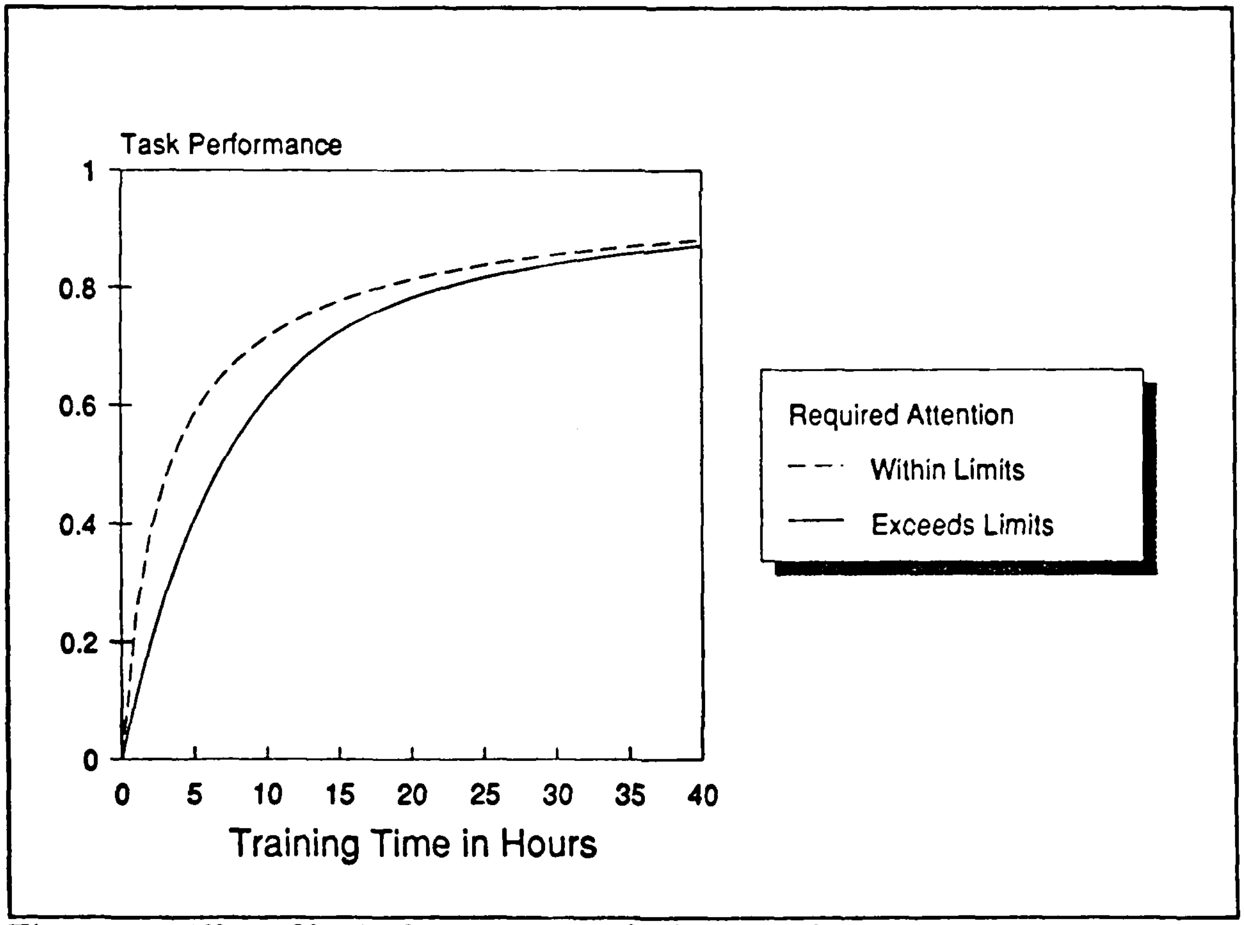


Figure 3. Effect of limited attention on the learning function.

It should be noted that the specific form of the function, f, in this development is hypothetical. We know of no research that has attempted to assess the form of this function; consequently, we have used the simplest form. Some research, such as that of Schneider and Shiffrin (1977; Shiffrin and Schneider, 1977), suggests that attentional requirements may decrease at a slower rate than is suggested by f. These results would suggest an even bigger effect of attention limits on learning rates. Such results could be incorporated by making the function, f, a power function. However, even in its simpler form, this example illustrates some of the possible effects of changes in the learning process due to attentional capacities.

Incorporating Cost Into the Composite Functions

The development so far has concentrated on performance as a function of training time. However, we may easily describe performance as a function of training cost, if there is a constant hourly training cost. The hourly training cost may incorporate an allocation of fixed cost items, as well as variable cost components. If h represents the hourly training cost, and d represents the total training cost, then we may rewrite Equation 3 to represent performance as a function of cost as follows:

$$P(d) = A\{1 - [1 + (C/h)(S' + d)]^{-k}\}, \tag{9}$$

where S' is the cost equivalent to previous experience. Equation 8 may be rewritten similarly.

The assumption of constant hourly training cost is a simplification, and does not allow us to consider such factors as economies of scale or discrete costs involved with the procurement of training devices. Nevertheless, within a restricted range of training hours, the assumption is probably reasonably accurate. Furthermore, for the purposes of this discussion, we prefer the simpler characterization of training cost, because we are not interested in training strategies that depend on details of the training cost function for their justification.

The Slope of the Cost-Effectiveness Functions

The optimal training strategy should maximize the gain in performance obtained from the training cost. That is, the training strategy should be based upon the derivative of Equation 9 for each training option under consideration. As the previous development has illustrated (in Equation 5), the derivative of the learning function can be expressed as a function of the performance level. The derivative of Equation 9 is shown below:

$$P'(d) = (AkC/h)(1 - P/A)^{(k+1)/k}. \tag{10}$$

Figure 4 illustrates this function for hypothetical skill-based and task-based training options ($S = 0.0$, $k = 0.7$, $h = 1.0$). The skill-based option approaches a lower asymptote ($A = 0.6$) than the task-based option ($A = 0.1$), but it approaches the asymptote at a higher rate ($C = 0.6$ vs. 0.1), perhaps because it compresses the training time required or because it requires a less expensive training device. The graph makes the optimal choice obvious; skill training should be chosen at low performance levels, while task training should be chosen at high performance levels. The remainder of this section specifies some of the conditions in which skill-training options might be optimal.

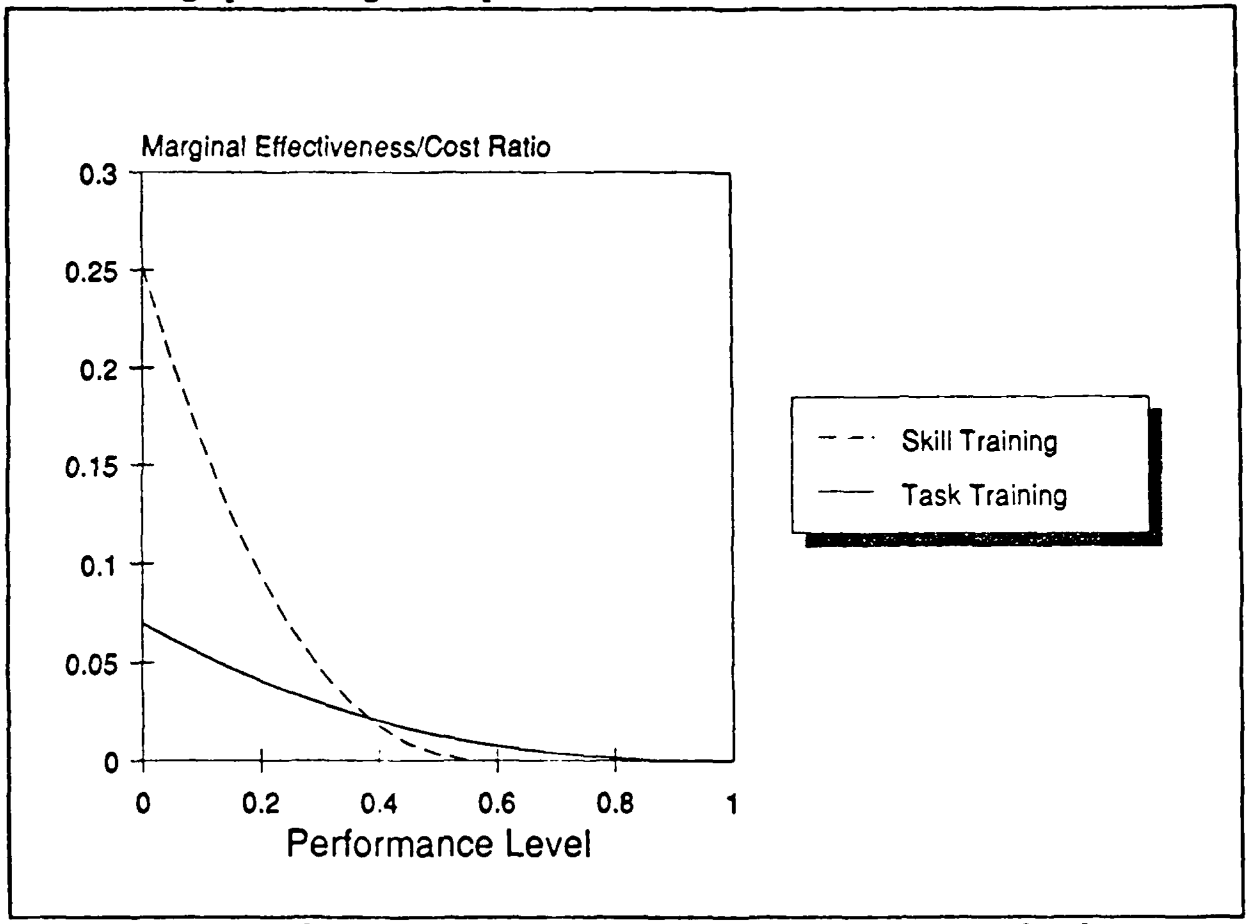


Figure 4. Marginal cost-effectiveness as a function of performance level.

Characterization of Skill-based Training Benefits

The framework presented above provides a way to illustrate the benefits that can occur from skill training. In addition, our analysis of skill-training benefits will enlighten us regarding the conditions under which the benefits of skill training should occur. We will use the framework to address possible three benefits of skill training. First, skill training can provide much more practice on a critical skill in a given amount of time or for a given cost. Second, critical skills can generalize to many tasks, so that training them can avoid unnecessary and redundant task training. Third, training the critical skills involved in complex

and difficult tasks can decrease the mental workload required to perform the tasks, and consequently speed up subsequent task learning. We will discuss each of these benefits, and will present graphs of that illustrate the types of learning and cost-effectiveness functions that can produce the benefit. Finally, we will enumerate some of the conditions that should maximize the likelihood that the benefits will be obtained.

Time Compression and Reduced Training Cost

Some tasks are structured so that there is little opportunity to practice critical skills. For example, one of the critical skills in air traffic control involves specifying the point where an aircraft should turn. As Schneider (1985) has pointed out, the skill required to specify the turn point correctly is very difficult to learn, both because of perceptual decay, and because the turn takes so long to perform that the student can only obtain a limited number of repetitions in a given amount of time. However, Vidulich, Yeh, and Schneider (1983) have shown that by isolating the skill in training, it is possible to get an increase of between one and two orders of magnitude in the number of practice iterations that are possible within a specified time.

Figure 5 illustrates the effect of a twenty-fold (just over one order of magnitude) increase in the number of trials per unit of time on the learning and cost-effectiveness functions (with $S = 0.0$, $k = 0.7$, $h = 1.0$). The effect of increasing the number of trials per unit time was accomplished by increasing the learning rate parameter, C, of the skill-learning function from 0.5 to 10.0. The asymptote of the skill-training curve was set at 0.3 to indicate that although the skill is critical for the task, it represents only one component ability required to perform the task. Nevertheless, the cost-effectiveness curve in Figure 5b indicates the superiority of skill training below a performance level of 0.18, which is 60% of the asymptote of the skill-training function.

The benefit of compression of training time may be enhanced if the skill training can be accomplished using a training device that is substantially less expensive to procure and operate than a training device required for task training. Here again, orders-of-magnitude improvements are possible. In the previous example, if the skill training could be conducted on a training device that cost 10% as much as a task trainer, then skill-based training would be optimal up to 86% of the asymptote of the skill-training function, or a task performance level of approximately 0.26.

Time compression can be a very powerful benefit of skill-based training. The power of this benefit comes from the fact that high levels of time compression may be possible. Several considerations must be made of the types of skill that must be possessed for successful job performance. Some of the factors that are required to obtain this type of benefit, or to enhance it, are listed below.

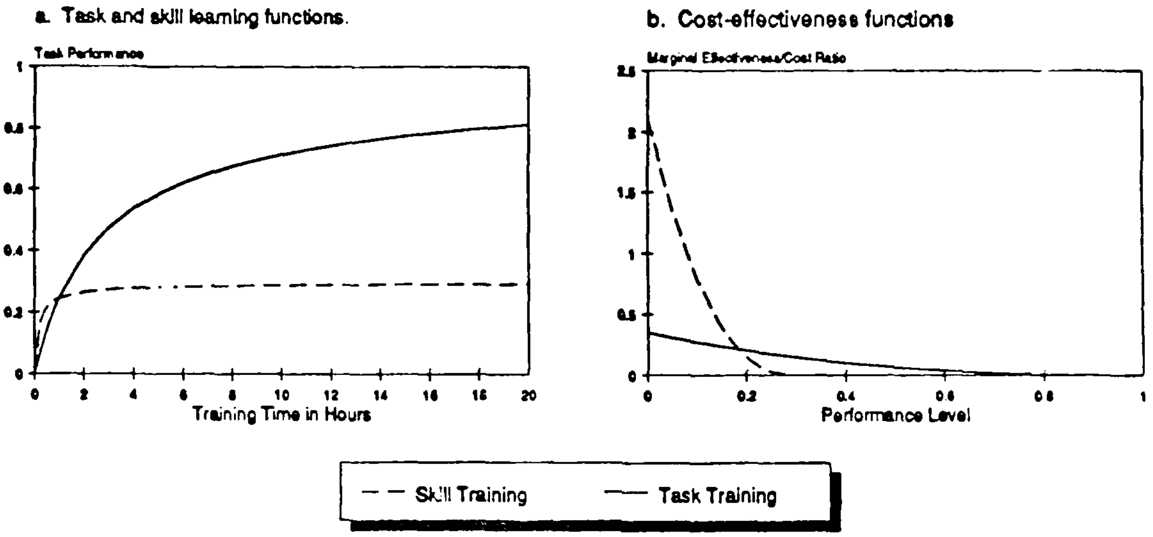


Figure 5. Learning and cost-effectiveness functions illustrating training time compression.

1. The effect of skill compression is enhanced if the skill being trained is critical to a task. High criticality leads to a high asymptote of the learning function, which, in turn, increases the marginal cost effectiveness as calculated in Equation 10.

2. The effect of skill compression is enhanced if the initial skill level is low. As Figure 5 illustrates, the advantage of skill training over task training decreases as a function of performance level. Thus, the benefits of skill training are maximized at low skill levels. At higher performance levels cost-effectiveness of skill training suffers because of imperfect transfer, related to the need to integrate skills.

3. Effective skill training requires that the skill can be isolated. For a skill to be trained in isolation, there must be a consistent mapping between stimuli and responses. By consistent mapping, we mean that the same stimulus situation produces same response. Since performance of activities with a consistent mapping does not depend on context variables the skill can be trained outside of the job context.

4. The benefit of time compression is that time can be saved by skill training. An order of magnitude improvement in training time is desired; otherwise, advantages may be lost due to imperfect transfer. A good indicator of candidate skills for time savings are those in which feedback is delayed. If skill training can reduce the delay period in which the learner is awaiting feedback, then not only will a greater number of training trials be possible within a period of time, but the trials are likely to be more effective because feedback is more immediate.

5. The benefit from time compression is enhanced if the skill can be trained with a training device that is less costly than the device normally required to train the task. Fidelity requirements for skill training must be inferred by an analysis of the activities by which a skill is instantiated, much as was done for tasks by the OSBATS models (Sticha, Blacksten, Buede, Singer, Gilligan, Mumaw, and Morrison, 1988). We expect that since skill training isolates the skill from the job context, and thus allows a much simplified representation of the job situation, it will usually require a less expensive training device.

Generalization

A second reason for skill training is that skills may generalize to several tasks, functions, and even new jobs. Thus, training several well chosen skills may enhance the performance of many job functions. The generalization of skills to job functions is somewhat more complex than time compression. In order to characterize skill generalization, we need to make several assumptions regarding how training will transfer among tasks and between skills and tasks. In our example, we first consider a single task and a single skill. Then we generalize the analysis to cover a single skill and several tasks.

Our illustration of the benefits of skill generalization is based on the following four assumptions: (a) A skill, as a single component of a task, transfers imperfectly to task performance. Thus, the asymptote of the curve relating skill training to task performance is less than one, depending on the relative criticality of the skill to the task; (b) since a skill is a single component of a task, it should be learned faster. That is, the learning rate should be higher for skill training than for task training; (c) because skill training does not incorporate the task performance context, the reduction in the asymptote will be greater than the increase in the learning rate; (d) skills can be learned during task training and transferred from one task to another. However, transfer of a skill acquired in the context of a task should be less than the transfer of training from skill-based training to task training. This result is expected because the skill training should produce more general learning that can be applied to a wider variety of situations than task training will produce.

Illustration of assumptions for a single task. The first three assumptions about skill generalization can be illustrated using a single task. First assume that

a single skill accounts for one-third (33%) of task performance. The skill training curve is obtained from the task training curve by increasing the learning rate, C, from 0.5 to 1.5 (assuming that the skill is learned roughly three times more easily, see b, above). We also reduce the asymptote, A, to account for assumptions (a) and (c) above. The decrease in A will be greater than the increase in C because there are two factors affecting the asymptote, while there is a single factor affecting the learning rate. In the example, we set A = 0.3 for the skill-training curve, which is 90% of what it would have been if the difference in the training context between skill training and task training had no effect (0.33, assuming that the skill comprised one-third of the task performance). Because we are investigating the effects of generalization, we will assume that there is no time compression. In determining the cost-effectiveness functions, we will simplify the problem and assume that the hourly training cost is the same for the two options.

The single-task learning and cost-effectiveness curves shown in Figure 6 indicate that there is no advantage to skill training at any performance level for this example. When the performance is at a minimal value (0.01), the slope of the skill learning function is 90% that of the task learning function, reflecting the effects of the difference in training context between skill training and task training (assumption c). As performance increases, the slope of the skill training curve decreases faster than that of the task training curve because of its lower asymptote.

Illustration of generalization for multiple tasks. Now we investigate the case in which the same skill is involved in several tasks. We consider two alternative training alternatives: (a) training a skill in a general context so that it will transfer to several tasks, or (b) training a skill in the specific contexts provided by the job tasks. For this illustration, we assume there are five tasks that require a given skill, and that the skill accounts for 33% of the performance of each of five tasks. We assume that in all other respects, the tasks are completely unrelated. Since learning the unique portion of each task is not affected by skill training, we will not consider it in the analysis. Rather, we will focus on the 33% that is common to all five tasks. Thus, this part of the example will not address the first two assumptions made above.

In keeping with assumption (c) made in the single-task case, we will assume that skill training transfers 90% to the common portion of the task. Since we are restricting our consideration to this common portion, we set the asymptote of the skill learning and transfer function to 0.9. The asymptote is set to 0.9, rather than 0.3 because we are ignoring the task-specific portions of each of the five tasks. This assignment means that when we train the specific skill in a general context, the learner is 90% of the way toward applying that skill in five specific contexts. Other parameters of the skill learning and transfer function are the same as was used in the single-task case (C = 1.5, S = 0.0, k = 0.7).

Assumption (d) of this analysis states that transfer of a skill from one specific context (or task) to another specific context will be less than the transfer

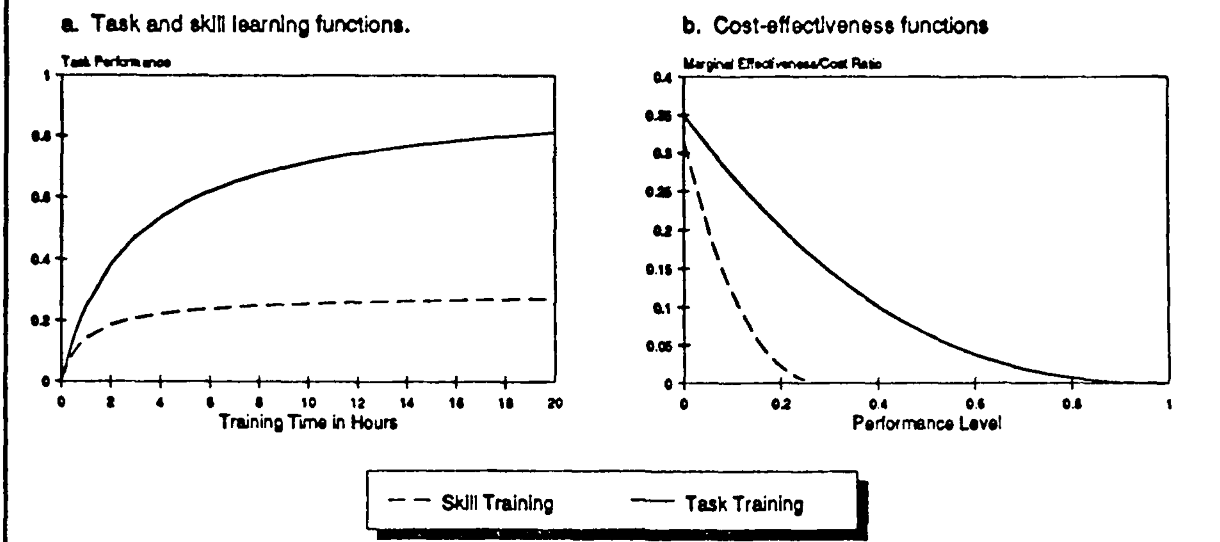


Figure 6. Single-task learning and cost-effectiveness functions assuming no time compression or reduced training cost.

of skill from a general context to a specific context. One way to arrive at an estimate of the parameter for transfer between tasks is to assume that transfer between tasks is represented by a two-step process. We start by assuming that the student learned the skill in a task-specific context. The first step re-encodes skilled performance in a general way based on the additional task performance requirements. Second, the general skill obtained by task training must be transferred to the new task. We assume that 90% of the skill learned in the original task-specific context will transfer to the general (multi-task) context. The second step is the same as transfer from skill training to task training, so we assume that 90% of the skill transfers. These assumptions do give an inherent advantage to skill training, but not an overwhelming advantage. We can then estimate the overall transfer from one specific context to another as the product of the transfer from the first specific context to the general context (at 90%) and the transfer from the general context to the second specific context (at 90%), for 81% transfer between tasks.

The assumptions described in the previous paragraph are used to calculate the parameters of the task training function in the following manner. The 81% of the skill that is common to all specific contexts will be learned once when the first

task is trained. The remaining 19% of the skill is specific to the task contexts; it will be learned separately for the initial task and each of the remaining four tasks. Thus, the total amount of general and specific skill to be learned is 0.81 + (5 x 0.19) = 1.76. This is only one way to estimate the amount to be trained, and is a conservative estimate. We set the learning rate, C, to reflect the fact there is more to be learned in task training than in skill training. Since the value of C for skill training is 1.5, we may adjust C to equal 1.5 ÷ 1.76 = 0.852. Since task training addresses the skill in all relevant contexts, we set A = 1.0. Other parameters are the same as for skill training (S = 0.0, k = 0.7).

The learning and cost-effectiveness functions that are derived from these assumptions are shown in Figure 7. The performance levels indicated for task training in the two graphs represent the arithmetic average performance level over the common portion of the five tasks. The results show a small difference between the learning functions representing skill training and task training. However, skill training has a cost-effectiveness advantage up to a performance level of about 0.6. At the minimal performance level, skill training has a 58% cost effectiveness advantage over task training.

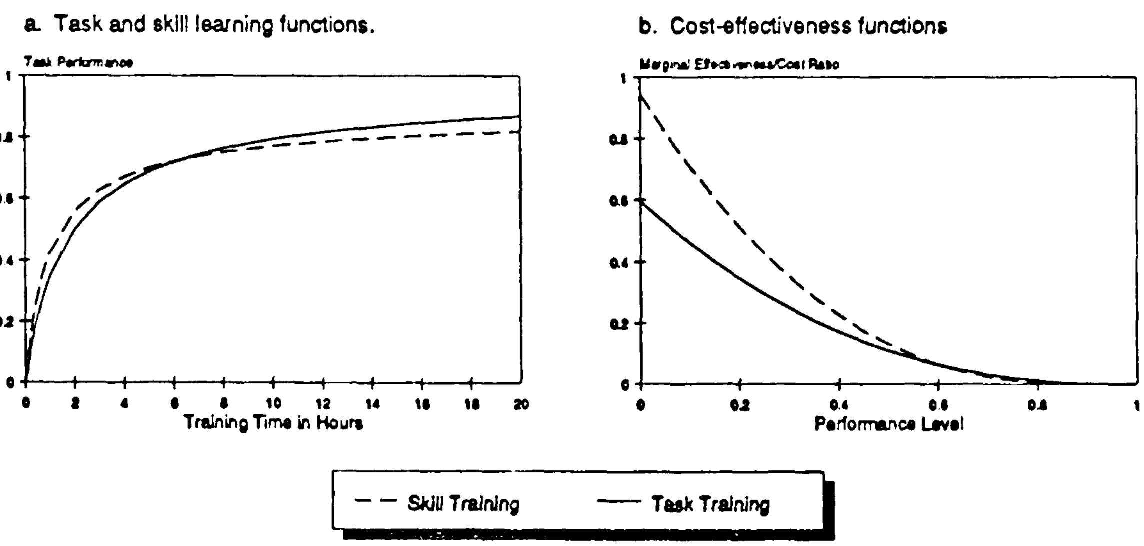


Figure 7. Multiple-task learning and cost-effectiveness functions assuming no time compression or reduced training cost.

The effect of generalization for this example was considerably less than the improvement that was obtained through time compression. However, the impact of skill generalization depends on the number of tasks to which skills will generalize, the skill-to-task transfer rate, and the task-to-task transfer rate. We assumed that both of the transfer rates were fairly high. If the task-to-task transfer rate were reduced from the assumed 81% to 0%, leaving the skill-to-task transfer rate at 90%, then the relative advantage of skill training would increase from 58% to 450%; if the rate were increased from 81% to 100%, then the advantage of skill training would be eliminated and task training would have a 10% advantage. A similar result occurs when skill-to-task transfer is changed. If this rate is reduced from its assumed 90% to below 57%, leaving the task-to-task transfer rate at 81%, then there is no advantage to skill training at any performance level.

The preceding analysis indicates some of the conditions that should occur for skill training to produce cost-effective training because of skill generalization.

1. The effect of skill generalization is enhanced if the initial performance level is low. As was the case for time compression, the maximum advantage for skill training occurs at low performance levels.

2. The effect of skill generalization is enhanced when a skill generalizes to a large number of tasks.

3. Effective skill generalization requires that the transfer of training from skill to task is high. Low transfer of training has the double effects of lowering the initial cost-effectiveness (at performance level 0.0) and increasing the rate at which cost-effectiveness decreases as a function of performance level. High skill-to-task transfer indicates that the context plays little role in the various instantiations of the skill. Hence, we would expect higher skill-to-task transfer for skills in which there is a consistent mapping between stimuli and responses.

4. The effect of skill generalization is enhanced if transfer from task to task is low. If transfer between tasks is sufficiently high, tasks may generalize directly as well as skills generalize to tasks. Hence, there would be little gained from skill training. We expect that tasks requiring cognitive skills, such as planning, would show low task-to-task transfer because the same planning heuristic often appears different in different situations.

Reduction of Attention Requirements

The final benefit of skill training to be discussed is its ability to alleviate the attentional demands in the early stages of training of complex tasks.

To illustrate the benefits of skill training for complex tasks, we will use the learning function that represent the effects of attentional limitations on learning.

We will assume that initially the task requires three times the attentional resources that the student has available (i.e., R = 3, L = 1 for task training). As the task is learned, the resources required gradually reduce, until at the performance level 0.67, the requirements are within the capabilities of the student. At that performance level, learning proceeds at its nominal rate.

Otherwise, our assumptions will be the same as were used in the single-task functions described in Figure 6. Specifically, for task training, we assume that C = 0.5, S = 0.0, k = 0.7, and A = 1.0. For skill training, we assume that C = 1.5, S = 0.0, k = 0.7, and A = 0.3. Furthermore, for skill training we assume that L > R. That is, the skill does not require so much attention to hinder learning.

Figure 8 shows the learning and cost-effectiveness functions for skill training and task training. To examine the effects of limited attention, this figure should be compared to Figure 6, which has the identical situation without any effects of limited attention. The skill training curves are the same in the two figures. However, the task training curves are noticeably different. In Figure 8, early task learning is considerably slower, because the attentional requrements of the task exceed the capacity of the student. Thus, skill training is cost-effective, even when a single task is considered, and there is no time compression or reduced training cost.

The advantage of skill training is fairly robust to changes in the asymptote of the skill learning curve or the task attention requirements. The asymptote must be lowered to 0.11 for the advantage of skill training to disappear. Similarly, the basic result remains, albeit at a reduced level, if the attention requirements are reduced to twice the student's attention capacity. It should be noted that the analysis does not recommend training the skill to automaticity. Rather, the skill is trained to roughly one-half of its asymptotic performance level.

Some of the conditions that are required to maximize the advantages of skill training to reduce attention requirements are enumerated below.

1. The major requirement is that the task is sufficiently complex to exceed the attentional capacity of the student during early learning. Such a task will require a long time to train. Early learning will be especially slow, and there may be deviations from the power law of learning at low performance levels.

2. The advantages of skill training are enhanced if the skill is critical to the task, unless the skill itself requires greater capacity than is possessed by the student. There may still be an advantage to skill training when the skill attention requirements exceed the capacity of the student, but the advantage will be reduced because the skill is learned at a slower rate.

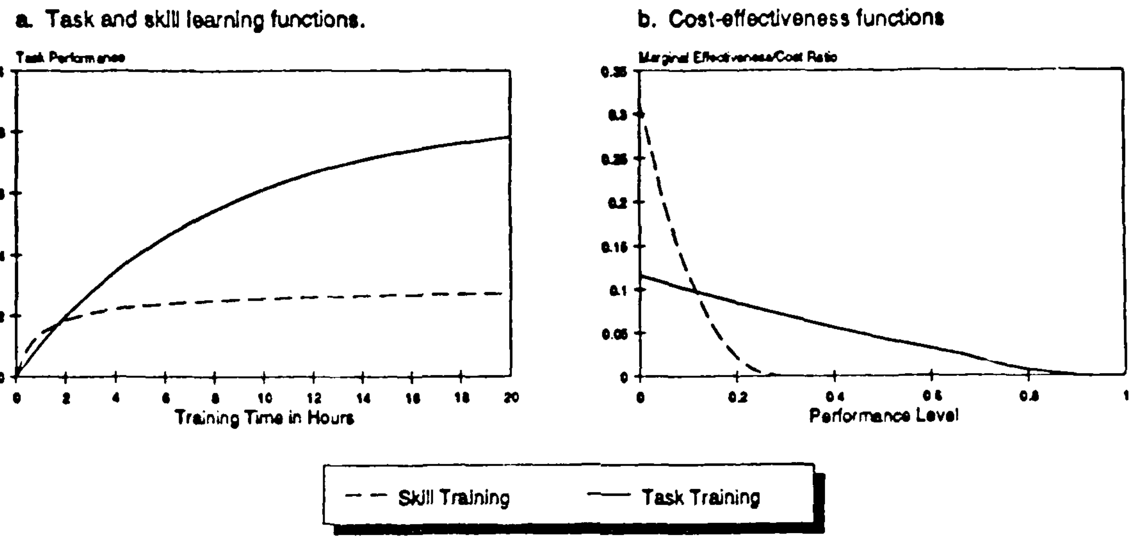


Figure 8. Learning and cost-effectiveness functions illustrating effects of attentional limits.

3. The advantages of skill training are greatest when the initial performance of the task is low. When the performance is low, the task requires the greatest resources to learn. Hence, there is the greatest advantage of skill training.

4. Reductions in attentional requirement seem to occur only for skills that involve consistent mapping between stimuli and responses (Shiffrin and Schneider, 1977; Schneider and Shiffrin, 1977). It is in these skills in which automatic processing is possible.

EXAMPLE OF SKILL-BASED TRAINING DESIGN MODEL

In our characterization of skills we outlined an approach for identifying skills for training outside of the job context, based on a body of research from educational and cognitive psychology. The rationale presented in the previous section described a theoretical framework for assessing the cost-effectiveness of skill training. Neither of these sections specified how our theoretical approach may be translated into practical application. Before describing the details of the skill-based optimization of training model, it would be a valuable exercise to provide a concrete example of the steps derived from that theoretical approach in the context of a real job domain.

The model breaks the specification of training strategies and devices into four steps: identifying skills, selecting instructional strategies, designing devices, and allocating training. The primary objective of the first step is to decompose tasks into their elements (i.e., performing actions upon objects), to identify the general abilities that enable the performer to accomplish the task, and to describe the domain-specific skills that will become candidates for skill-based training. The main goal of the second step is to group and sequence skills for training. In the third step, device requirements are derived from the nature of the skills to be taught. These requirements include instructional capabilities, interface features, and memory requirements. The final activity compares the projected cost of task training to that of task training supplemented by the proposed skill training. The example will focus on the major aspects of the first two steps. The third and fourth steps will be described in less detail, as a complete description of these activities would require a more thorough description of the first two activities than is practical for an example.

Description of the Job Domain

The example we use is from the Air Traffic Control (ATC) domain. We have chosen ATC to use as an example for several reasons. First, we wanted to demonstrate the value of skill-based training in a domain that has direct relevance to the Army. Second, we wanted a domain with which we have some familiarity. ATC is a job that we have examined in some detail, and we can, therefore, work the example without the assistance of subject-matter experts. Third, ATC requires skills corresponding to each ability category (i.e., cognitive, perceptual, psychomotor). ATC is a highly complex real-time job that demands planning and decision-making skills as well as finely tuned perceptual and motor skills. This fact is important since the training research and development disciplines are just beginning to recognize the role of cognitive skills in performance. Consequently, cognitive skill training is becoming a more central component of instruction. Finally, the domain has a clear task structure and a sophisticated environment that allows issues of fidelity and instructional context to be explored.

The example uses as a point of departure a task analysis performed for the Federal Aviation Administration on the job of en route ATC (DOT/FAA/AP-87-01 (Vol#6), Ammerman, Bergen, Davies, Hostetler, Inman, & Jones, 1987). The FAA analysis was used because an investigation of the ATC course as taught in the Army (MOS 93C) revealed that many of the tasks were referenced to FAA standards. The task analysis was conducted to provide input to the development of new ATC equipment, procedures, and instruction. The analysis identified 348 controller tasks. Each task is defined in terms of information (input/output) requirements, frequency and criticality of the task, cognitive and sensory attributes (general ability categories), and performance criteria (time and accuracy). For the most part, the cognitive and sensory attribute list shown in Table 2 is a subset of our general ability taxonomy (Table 1). Since our taxonomy is a more complete list we will draw upon it in the example.

Tasks are specified at the level of what needs to get done (the goal) rather than how it gets done. At this level of description, the skills required to perform the task cannot be determined. To identify how tasks are accomplished and, therefore, the skills required, tasks were decomposed into <u>task elements</u> describing the procedural steps and actions used in accomplishing the task. Task elements are statements containing a verb, which specifies some action, and one or more nouns representing the object on which the action is taken; modifiers are included for clarity. The list of task element verbs is organized into a hierarchical verb taxonomy (Figure 9), and each verb is defined in a task element verb glossary (see Ammerman, et al., 1987).

<u>Identify Skills for Training</u>

Since tasks have been characterized in terms of the abilities required to perform them and domain-specific actions, objects, procedures, and input/output information, it should be possible to derive the job skills associated with various tasks in a systematic way. In addition, frequency and criticality ratings obtained for each task and the recurrence of task element actions across tasks should provide a way of selecting those skills most appropriate for skill-based training.

In some cases, identifying job skills will be straightforward due to the close correspondence of task element verbs to items in the ability taxonomy (e.g., the verb "scan" and the ability spatial scanning). In other cases, it will be more difficult to match verbs with abilities (e.g., the verb "project" can be accomplished by visualization or through reasoning processes). The source of the identification problem is that a task element statement can use a verb from any level in the hierarchy. In the glossary, however, higher level verbs are defined only in terms of their descendants. For example, to <u>acquire</u> is defined as perceive via detection, scanning, search, extraction, or cross-reference. Since each of these low-level verbs can correspond to a different kind of cognitive or perceptual ability, it would be impossible to match a task element statement containing the verb acquire with a particular skill. In these ambiguous situations, more detailed knowledge of the

Table 2
List of Cognitive/Sensory Attributes (from DOT/FAA/AP-87-01 (Vol#1))

Coding	Transformation or translation of information for entry into the system; converting textual information to graphics or symbols.
Decoding	Transformation or translation of information received.
Deductive Reasoning	Ability to reach a conclusion that follows logically from the known facts or data; selection from among alternative answers or methods.
Filtering	Selection of inputs on which to focus attention in the presence of distracting stimuli or high workload; selective attention; overload accommodation.
Image/Pattern Recognition	Perception of spatial patterns and relations among static or dynamic visual inputs. May involve orienting oneself to the position or configuration.
Inductive Reasoning	Generation of an explanation for a set of specific data or instances, giving structure and meaning to the information; Generalization of working hypotheses from specific events; ... ability to make a knowledgeable assumption using incomplete data.
Long-Term Memory	Mental storage of knowledge over a period of time and selective recall of items relevant to the situation.
Mathematical/ Probabilistic Reasoning	Translation of uncertainty into probability; assigning a subjective probability regarding the likelihood of an event occurring, ability to use probabilities to identify optimal courses of action.
Movement Detection	Recognition of the physical movement of a visual object; estimation of its direction or speed.
Prioritizing	Ordering of events in sequence; establishing priorities.
Short-Term Memory	Mental storage and selective recall of relevant information over a brief period of time.
Spatial Scanning	Rapid identification or detection of objects or events displayed in a wide or complicated visual field.
Verbal Filtering	Same as Filtering, but limited to voice communications.
Visualization	Observation of spatial patterns and subsequent mental transformations into other spatial patterns.

USER-INTERNAL TAXONOMY		
PERCEIVE	ACQUIRE	DETECT SEARCH SCAN EXTRACT CROSS-REFERENCE
	IDENTIFY	DISCRIMINATE RECOGNIZE
MEDIATE	ANALYZE	CATEGORIZE CALCULATE ITEMIZE TABULATE
	SYNTHESIZE	ESTIMATE INTERPOLATE TRANSLATE INTEGRATE FORMULATE PROJECT/ EXTRAPOLATE
	ASSESS	COMPARE EVALUATE
	DECIDE	
COMMUNICATE	TRANSMIT	CALL ACKNOWLEDGE RESPOND SUGGEST DIRECT INFORM INSTRUCT REQUEST
	RECEIVE	

USER-INPUT TAXONOMY		
CREATE	ASSOCIATE	NAME GROUP
	INTRODUCE	INSERT
	ASSEMBLE	AGGREGATE OVERLAY
	REPLICATE	COPY INSTANCE
INDICATE	INITIATE	
	REFERENCE	
ELIMINATE	REMOVE	CUT DELETE
	STOP	SUSPEND TERMINATE
	DISASSOCIATE	RENAME UNGROUP
	DISASSEMBLE	SEGREGATE FILTER
	SUPPRESS	
	SET-ASIDE	
MANIPULATE	TRANSFORM (CHANGE ATTRIBUTE)	
ACTIVATE	PERFORM (__ TEM)	
	EXECUTE (__ FUNCTION)	

Figure 9. Task element verb taxonomy (from DOT/FAA/AP-87-01 (Vol #1)).

job domain is needed to infer the proper job skill. This knowledge can be supplied by subject-matter experts or through supplemental job analysis.

Identify Tasks

Tasks are selected for consideration based on three criteria: entry-level performance, training time, and workload. These constructs are described in our formal model description and will not be discussed further here. For the example, we have selected one of the en route radar controller's major responsibilities, ensuring that aircraft are separated from each other and airspace boundaries according to prescribed separation standards. Part of this responsibility is superordinate Task A1.1.1: Checking and Evaluating Separation (Ammerman, et al., 1987). The purpose of Task A1.1.1 is to anticipate potential conflicts between aircraft before separation is lost. In general, this is done by monitoring radar tracks on the Plan View Display (PVD), or radar scope, and/or by gathering and interpreting data from several sources (i.e, data blocks, flight progress strips) concerning the route of flight, altitude, speed, and estimated time at various intervals for each aircraft in (or about to enter) the sector.

Task A1.1.1 involves fifteen subordinate tasks and a total of 116 task elements. Three of those tasks are listed in Table 3. We will use this set of tasks to illustrate the skill identification process. Many of the task elements are highly similar within and across these subordinate tasks. In fact, across the 116 elements there are only 13 unique verbs. The unique task element verbs associated with each task in Table 3 are listed beneath each task statement. Also listed are the cognitive/sensory attributes associated with the task. Note that although the verb lists are very similar across these tasks, the attribute lists vary significantly.

Identify General Abilities

We begin the process by reviewing each task element, attempting to identify the general abilities characterized by the task element verb. The first step is to identify the abilities in the ability taxonomy (Table 1) that might be involved in performing the action specified by the task element verb. While it may seem possible to simply match verbs in the verb taxonomy to abilities in the general ability taxonomy, in practice there is no straightforward mapping scheme. The mapping often depends upon the context of the particular task. Identifying the appropriate ability can require domain-specific knowledge that is not supplied by the verbs alone.

Search. The first verb in Table 3 is "search," which is defined as "purposeful looking over a display or area to locate a specific item or items." An example of a task element containing this verb is A1.1.1.30.2:

> Search flight progress strip in flight strip bay for information pertaining to aircraft separation.

Table 3
Partial Task List for A1.1.1, Checking and Evaluating Separation

A1.1.1.2	Review plan view display for potential violation of aircraft separation standards.	
Task Element Verbs:		Cognitive/Sensory Attributes:
	search	movement detection
	perceive	spatial scanning
	extract	filtering
	synthesize	visualization
	recognize	inductive reasoning
		math/prob reasoning
A1.1.1.4	Project mentally an aircraft's future position/altitude/path.	
Task Element Verbs:		Cognitive/Sensory Attributes:
	search	visualization
	extract	short-term memory
	synthesize	inductive reasoning
	project	
A1.1.1.30	Review flight progress strips for present and/or future aircraft separation.	
Task Element Verbs:		Cognitive/Sensory Attributes:
	search	spatial scanning
	extract	decoding
	synthesize	visualization
	recognize	short-term memory
		inductive reasoning
		math/prob reasoning
		prioritizing

Searching for a specific item can involve several abilities, including detection, pattern recognition, selective attention (filtering), and/or discrimination. We must ask which ability or abilities apply in the context of the particular task element. Detection can be eliminated because skill acquisition in detection is only an issue when stimuli are difficult to detect. The objects to be detected in this case, flight strip data fields, are easily discernable. Discrimination requires two or more objects to discriminate and a list of attributes on which the discrimination is based. This task element does not have these components. Selective attention is generally associated with vigilance monitoring tasks, in which a target stimulus must be detected against a background of competing stimuli. Again, this is not the case. The only ability that would reliably distinguish among levels of performance is pattern recognition.

The pattern is defined by the object(s) in the environment associated with the task element, the area of regard, and the information processing modality. For this task element, the objects are alphanumeric flight strip data fields, the area of regard is the flight strip bay, and the modality is visual. The result is the location of a specific data field or fields.

Having gone through this process, we can generalize that any "search" task element having the same class of objects, area of regard, and modality will require the same general ability. An example would be task element A1.1.1.31.1:

> Search flight progress strip in flight strip bay for information pertaining to potential violation of flow restrictions.

However, all tasks elements containing a particular verb may not invoke the same set of abilities. It is important to distinguish among classes of objects to which the task action is applied when identifying abilities. "Search" task elements can involve abilities other than alphanumeric pattern recognition as in the following example, A1.1.1.2.1:

> Search primary target, data block for potential violation of aircraft separation standards.

Primary targets, or blips, can appear anywhere on the radar display at any time among a great deal of "clutter." Consequently, detection becomes a factor in the search for targets. This is not true for data blocks, which like flight strips are readily discernable.

Perceive. The next task element verb on the list (under A1.1.1.2, Table 3) is "perceive." Unfortunately, the three top-level verbs in the task-element taxonomy—perceive, mediate, and communicate—are not defined in the task-element verb glossary; they are only category titles. The task element in which it is used is A1.1.1.2.2.1:

> Perceive plan view mental traffic picture from target position symbol, track status symbol, track history, velocity vector on plan view display.

The fact that a top-level verb is used in a task element reveals that the mental processes involved are not well-understood. Any or all of the lower-level perceptual verbs may be involved. Based on an understanding of the objects in this task element and the kinds of information they convey (e.g., controllers can determine direction of flight and derive speed estimates from track history) we can reason that this task involves quantitative estimation, inductive reasoning, spatial reasoning, and/or visualization. We would require more information to make a definite determination, and defer any recommendations until more detailed analysis is conducted.

Extract. The next verb from Table 3, "extract," is defined by Ammerman, et al. (1987) as "directed, attentive reading, observing, or listening with the purpose of gleaning the meaning or contents thereof." A sample task element statement is A1.1.1.30.3.3:

> Extract route information, previous posted fix, posted fix, next posted fix from flight progress strip.

In this data set, extraction is generally associated with search. It encodes the meaning of an item in active memory and serves to complete the search. Extraction of meaning can be indicative of verbal comprehension or perceptual pattern recognition ability. By definition, it can involve either visual or auditory modality. In the sample statement, however, the objects are alphanumeric data of specific values found in flight data fields and identified by the visual search process. Therefore, the extraction of meaning is more appropriately associated with the internal (mental) modality.

Synthesize. The verb "synthesize" is a mid-level verb that is defined by Ammerman, et al. (1987) as mentally producing new information via estimation, interpolation, translation, integration, formulation, or projection (its subordinate verbs). Again, it is clear that this definition leaves room for several kinds of skills. To determine which are appropriate we must examine specific task element statements. One such statement is A1.1.1.30.4:

> Synthesize position, route, speed, altitude, and time information into a mental picture of aircraft separation.

In this statement, the objects are alphanumeric information extracted from flight strip data fields. To determine the modality it is necessary to look at the context of prior task element statements. Since those statements are "extracts," we can assume that the information resides in active memory; thus the modality is internal. Given that the product of the synthesis is a mental picture, we can assume that at a minimum, translation (changing from one representational system to another) and integration (mentally organizing a variety of data) are involved. The general abilities that underlie these processes are abstraction and spatial reasoning. If, indeed, an analog mental picture is formed then visualization would also be a candidate.

Recognize. The next verb from Table 3, "recognize," is defined by Ammerman et al. (1987) as "specific, positive identification of an entity." A statement containing this verb is A1.1.1.2.4:

> Recognize potential violation of separation standards.

This is another instance in which context is important. On the surface, this verb is indicative of pattern recognition ability. As we found in the case of "search" and "extract," however, pattern recognition can refer to different classes

of objects across modalities. In this case, the target pattern, or object, is a spatial mapping of aircraft in an internal (mental) picture of the airspace. Also implicit in the statement is the ability to encode and recall separation standards, or rules, stored in long-term memory. Hence, this verb also characterizes the interpretation of a data pattern according to established rules, or deduction.

Identify Skills

Based on this analysis of task element statements we have identified several general abilities that underlie performance on Task A1.1.1, the conditions under which those abilities are invoked, and the environment in which they are applied. We have discovered that at the level of detail specified in the FAA analysis, tasks and even task elements do not unambiguously distinguish among skills (i.e., there exists no one-to-one mapping). Having identified the general abilities, we can now trace back and translate this information into job skills.

Keeping in mind our goal of developing skill-based training formats, we would not want to define skills so specifically as to distinguish among all task elements. Rather, we want to identify skills that apply across task elements. To accomplish this, we have created a skill frame hierarchy:

verb (modality)
- ability
  - area of regard
    - task object category: objects

A skill is defined as the application of an ability to a class of objects in an area of regard. When a new task element is encountered, the information contained in it can be compared to existing data and, if necessary, added to the hierarchy. We acknowledge the bottom-up nature of the process; development of the frame structure is driven by the available data. The more data sets the model is applied to, the more complete the frame hierarchy will become.

Below are the frames identified for the task action verbs search, extract, synthesize, and recognize.

Search (visual)
- pattern recognition
  - radar display
    - graphic: track history, velocity vector
    - field: data block
    - text: flight data
  - flight strip bay
    - field: flight data fields
    - text: flight data

detection
radar display
graphic: primary target

Some skills correspond to information gathering activities. We have identified two such skills associated with the task element search: detecting primary targets on the radar display and recognizing various kinds of consistently mapped patterns. For pattern recognition, we identified two areas of regard: the flight strip bay and the radar display. Objects within these two areas were of three types: graphic symbols, text, and data fields. The modality was visual. We can, therefore, conclude that an important job skill is having some proficiency at identifying those objects in their respective contexts. For certain graphic symbols (i.e., primary targets) it is also important to develop skill at detecting the symbols against a background of competing symbols in variable locations.

Extract (visual)
verbal comprehension
flight strip data field
text: route info, previous posted fix, posted fix, next posted fix

Another important information gathering skill is the ability to comprehend the meaning of information. For example, the numeral 220 in the flight progress strip altitude data field means that the aircraft is flying at 22,000 feet. In another field it may mean a heading of 220 degrees. Controllers must be able to interpret information in the surrounding context.

Synthesize (internal)
abstraction
text: route, speed, altitude, time
spatial reasoning
mental representation: aircraft relationships
visualization
mental image: analog picture of airspace

Recognize (internal)
information recall
rules: separation standards
deduction
data: actual separation, min legal separation

At a higher level, controllers must have information manipulation skills. We have identified the ability to estimate distance based upon speed and time data and to estimate speed based on history markings. These skills, in turn, allow controllers to make spatial judgments and comparisons, such as determining the intersection of two flight paths or whether an established rule has been violated.

Skill Training Strategies

We have argued that skill-based training is intended to complement task-based training. After identifying a set of job skills, the next step is to determine which are appropriate for skill-based training, and which are more appropriately taught in a task context. Some of the factors that should be considered are:

- level of training effort
- consistency across instances
- level of contextual dependence
- frequency of use on the job
- criticality to job performance
- level of proficiency required by the job

When a skill is narrowly defined or requires few mental resources to acquire, it may be more cost-effective to incorporate its instruction into task-based lessons. An example might be the ability to read time from the military clock on the radar display. Skills whose application are highly context-dependent may also be better candidates for a job task environment. Conversely, skills that apply more generally across tasks and those that require much effort to acquire are better taught, at least initially, in a skill-based environment.

Frequency and criticality are also important factors. Generally, the more critical the skill is to job proficiency, the more training should emphasize the development of that skill. Similarly, the more frequently one is called upon to use a skill, the more likely initial skill training will enhance learning. Confounded with these factors is the target proficiency level. Are errors tolerated? Is speed a factor? Must the task be performed concurrently with other more or less demanding tasks? Skills that must be applied without sapping attentional resources (automatic processes) require many more practice trials to develop than are generally given in task-based training.

Skill training strategies specify the skills that should be trained together, the level of performance to which skills should be trained, and how to sequence training. Grouping skills for training is based upon category similarity in the skill frame hierarchy. For example, recognizing data fields on flight strips might be grouped with comprehension of the text in each field. This might be followed by training on data block fields. Since these skills are applied on objects which are consistently mapped (e.g., 220 in the altitude field always means 22,000 feet) the performance criterion would be high. An example of sequencing would be training information gathering skills, followed by training on information manipulation skills such as abstraction of the data into a mental representation of aircraft positions, and training on spatial reasoning about that representation.

A device used to provide training on the specified skill strategies requires certain interface and instructional features to be successful. The final step in the development of the skill strategies is to determine the instructor support and

interface requirements associated with each skill strategy. These two kinds of requirements are determined through the use of rules that specify requirements as a function of general ability, modality, skill objects, training criterion, sequencing method, student entry characteristics, and the domain knowledge of the training designer or subject-matter expert. The requirements provide the major control for the design of skill-training devices described in the following section.

Instructor support features are elements of training devices that aid the instructional process, producing more efficient training. Examples of instructor support features include scenario control, performance measurement, augmented feedback, augmented cues, and performance recording and playback. Factors to consider are primarily the basic ability required by the skill, student skill level, and the skill training criterion. For example a detection task can benefit from the use of augmented cues, but only when the student entry skills are low. Other instructor support features are appropriate for other types of skills or when the skill training criterion is high. Thus, there is a set of rules that we may use to determine the instructor support requirements for each skill strategy.

Interface requirements, like instructor support requirements, are determined by a set of rules that recommend interface features based on skill information. Most interface requirements come from the need to present cues such as visual displays and instrument readings, to provide controls for learner responses, and to present response feedback. Interface requirements are based primarily on the basic ability, modality, skill objects, and domain information provided by subject-matter experts. For example, the group of skills involving recognition of the data fields on a flight strip requires a text display, because the fields on the flight strip are textual information. Training these skills does not require a simulation capability because the flight strip is a static display.

Design Skill-Training Devices

The previous analysis has produced training strategies that include groups of skills and their associated instructor support and interface requirements. A variety of training devices of several different categories could be used to implement the training strategies. Some of the categories of training device are well-defined technologies with known options. Examples of these general-purpose technologies are computer-based instruction (CBI), panel trainers, and control procedure trainers. These trainer categories provide general capabilities that may be adequate to implement many of the skill-training strategies. Other strategies will require the design of special-purpose training devices or simulators tailored to their specific device requirements.

The procedure for choosing a design of a training device from a general device category is similar in many respects to the procedure for designing a special-purpose training device. In each case, the device consists of several components in which there are design options. These design options reflect the

sophistication of displays, the amount of interactive control, the processing power, the peripheral devices, and other features. The design options vary in their cost and sophistication, as well as in their capability to meet the requirement of the skill strategies. To be effective a design must meet the interface and instructor support requirements of the skill strategies that are to be implemented on the device.

The major difference between the processes of choosing the design of a general-purpose device and developing the design for a special-purpose device is in the number and range of options available. General-purpose training devices have a limited number of relatively well-defined design options. However, the range of options is much wider for special-purpose devices. In each case, the task is to select the design that meets the requirements of skill strategies at the minimum cost.

The procedure we describe begins by analyzing general-purpose training devices and ordering on increasing cost. For each training-device category, the skill groups are identified that could be trained by the most sophisticated training device in that category. This cluster of skill groups is used to evaluate the device-category interface and instructor support options. Each option receives benefit according to the number of skill groups for which it meets or exceeds the requirements.

As an example of the design skill-training devices activity we shall consider the design of a CBI system. The components for such a system include text and graphic visual displays, keyboard and pointing input devices, moderate computation and simulation capabilities, and possibly access to video images. After sorting through the skills that have been assigned skill training strategies, a list of skills groups for this type of device might contain the following:

- Recognition of data fields on a data strip and in data block
- Comprehension of data in a field
- Detection of targets on a radar display
- Abstraction of a mental representation of aircraft data
- Spatial reasoning (e.g., projection of a future position for an aircraft)

The second activity required to design skill-training devices is to identify instructional features, and to develop costs and benefits for them. These benefits and costs can be used to develop benefit to cost ratios, which can be used to rank and select features addressing the skill groups. Exemplary features include cue augmentation, feedback, and monitoring. The requirements for instructional support features for each skill group are examined, and each instructional support feature can receive a benefit in proportion to the number of skill groups which the feature addresses. The addressed skill groups contribute a weight to this calculation according to their criticality and training need. Instructional support features can then be selected according to the ratio of this measure of benefit to their cost.

The third activity selects interface features by device and produces costs and benefits for options within several of the device's interface components. These assigned benefits and costs can be used to rank and select the interface features, as was proposed with instructional features. The category of device being considered limits the range of components and the options within each component. For example, display size is an interface component having several options, including standard, large and projection. While many other display sizes are possible, these three options represent the major alternatives possible with computer-based devices. Display characteristics, another component, has several options: text only, text or graphics, text and graphics in monochrome, in color, and in high resolution color. Components which may either be present or absent include the pointing device and stored video images. The computation capabilities could be designated by the processor type (e.g., 8088, 80286, 80386, and 80486) and speed (e.g., 8, 12, 16, 20, or 33 MegaHertz). Finally the options for simulation capability could be none, commercial off-the-shelf package, a CBI system, and specialized software.

The benefit of an option for a component can be determined by comparing the capability of the option to the interface requirements for each skill group. In general, there will be a direct correspondence between device components and interface dimensions. The benefit of any option can be the weighted number of skill groups for which the capability of the option is greater than the requirement of the skill group on the relevant interface dimension. The skill groups are weighted by their criticality and training need, as above. The index of merit for each component option can be the incremental benefit divided by the incremental cost of the option. The result of this activity is the prioritized set of device options, based on a cost-benefit analysis.

The fourth activity determines the priorities of the device interface options and instructional features based upon their relative benefit-to-cost ratios. The designer then selects the device design based upon a desired cost or benefit level to be achieved. An illustrative device design for $5000 and 75% of the total skill training benefit might be:

Text and/or graphics, color
Standard display size
Pointing Device
No video
80386 processor
No simulation capability
Cue augmentation

The capabilities of this device can then be examined in light of its ability to train the above skills. If the requirements of skill groups are not adequately met by the device design, then the designer may either choose a more sophisticated device design, or decide to train the skill groups on another device.

After completing the analysis of this device, the process would be employed for other device categories with greater cost. The recommended device design for each category provides the input to the allocate training resources activity.

Allocate Training Resources

When the previous activity is completed for all skill-training strategies, there is a collection of skill-training devices defined for different strategies. Although skills were selected because of the potential for cost-effective skill training, we would not expect all of the proposed skill-training devices to provide cost-effective training in comparison to task-based training devices. This activity compares the projected cost of training using task training only to the projected cost of training when task training is supplemented by skill-training.

The activity proceeds in four steps. The first two steps determine the cost of task training and the cost of implementing each skill training strategy. The analysis of skill training performed in the second step also determines the skill levels produced by skill training. These skill levels have an effect on the entry performance level to task training, thus reducing the task-training requirement. The third step in the analysis determines the impact of skill training on the cost of subsequent task training. Finally, the fourth step determines those skill-training strategies that produce a net improvement in overall training cost, and selects these strategies.

A MODEL FOR SKILL-BASED TRAINING DESIGN

Introduction

The goal of the model is to combine knowledge about the nature of skills and skill acquisition with concepts of the cost-effectiveness of skill training to produce a method that can be applied to problems of training development and training system design. The model must consider (a) the goals of the decision making process for skill-based training system design, (b) the specific training requirements, (c) the nature of the skills required for the job being trained, and (d) the design factors that decrease cost or improve effectiveness.

As a first step in the model development process, we identified who the principal users are, and what their needs are. Given this knowledge, we then designed the model with the needs of the user in mind. We considered the following four potential users.

1. The training designer responsible for determining training requirements and producing a training design,

2. The training-device designer, responsible for converting training requirements into training-device design specifications,

3. Research laboratories, responsible for developing new and innovative solutions to training problems, and

4. Source selection evaluation boards, responsible for evaluating the training component of a weapon system being procured.

Each of these users has somewhat different concerns regarding skill-based training options. In addition, the model will rely on a subject-matter expert, such as an instructor or job incumbent, to provide some of the required input data. We considered the following four questions to represent issues that could be addressed by the model.

1. Given a set of training requirements, which skills should be trained isolated from the job context?

2. Given a set of training requirements and skills to be trained, what training strategies should be employed? Training strategies specify what to train, the training sequence, and the criterion performance level. They form the basis of training device requirements.

3. Given a skill-training strategy, what interface and instructional features should be incorporated into a training device that is used to implement the strategy?

4. Given a set of training requirements, skills, and training devices, how should training time be allocated between task and skill training on training devices or actual equipment to meet the training requirements for the least cost?

Table 4 shows our assessments of which questions are concerns of each type of user.

Table 4
Questions of Concern to Potential Model Users

	User Category			
Questions Selection	Training Designer	Device Designer	Research Laboratory	Source
Select Skills for Training	X	X	X	
Select Training Strategies	X	X	X	
Design Training Devices	X	X	X	X
Allocate Training Time	X		X	

In developing the model, we took the viewpoint of the training designer, because that class of user has the broadest concern with skill-based training system design issues. The design engineer also had many of these concerns, depending on what information was present to support the training device requirement.

The process of model development involves specification of model processes and data in increasing levels of detail. We present the model as an IDEF0 activity model. The IDEF0 model describes the activities included in the model, the data required, and the output produced by the model.

The section continues with a description of the IDEF0 system description methodology. Then, we present a description of the skill-based design model activities.

IDEF0 Methodology Description

IDEF0 (Integrated Computer Aided Manufacturing Definition) was developed by the Integrated Computer Aided Manufacturing Office (ICAM) of the U.S. Air Force to be used as a tool for describing the functions and data of a complex system (SofTech, Inc., 1981; Ross & Schoman, 1977). A system consists of any combination of machinery (hardware), data, and people, working together to perform a useful function. IDEF0 is a technique that enables people to understand complex systems and to communicate their understanding to others. IDEF0 describes the functions performed by the system by successively decomposing the system into its basic components, describing how each component processes information, and specifying how different components interact. An IDEF0 model is expressed as a series of related diagrams; each diagram describes a particular system component or function. An IDEF0 diagram is composed of boxes and arrows. The boxes represent component functions or activities, while the arrows represent data that affect the activities or are produced by them. In this report, IDEF0 is used to describe the components and functions of the skill-based training system design model.

IDEF0 Model Organization

The diagrams in an IDEF0 model describe the system in a modular, top-down fashion, showing the breakdown of the system into its component parts. The application of IDEF0 starts with the most general or abstract description of the system to be produced. This description is represented in a diagram as a single box; that box is subsequently broken down into a number of more detailed boxes, each of which represents a component part. The component parts are then detailed, each on another diagram. Each part shown on a detail diagram is again broken down, and so forth, until the system is described to the desired level of detail. Lower-level diagrams, then, are detailed breakdowns of higher-level diagrams. At each stage of breaking down the system, the higher-level diagram is said to be the "parent" or overview of the lower-level "detail" diagrams. The relationship between diagrams at different levels is shown in Figure 10.

Diagram display format

In this document, each diagram in an IDEF0 model is displayed in a two-page format. The subject diagram is shown on the top of the right-hand page. The parent of the subject diagram is shown on the top of the left-hand page with the location of the subject node indicated. On the bottom half of both pages is text describing the operations performed by each activity represented in the diagram. Each pair of pages receives a page number that is displayed as part of the subject diagram.

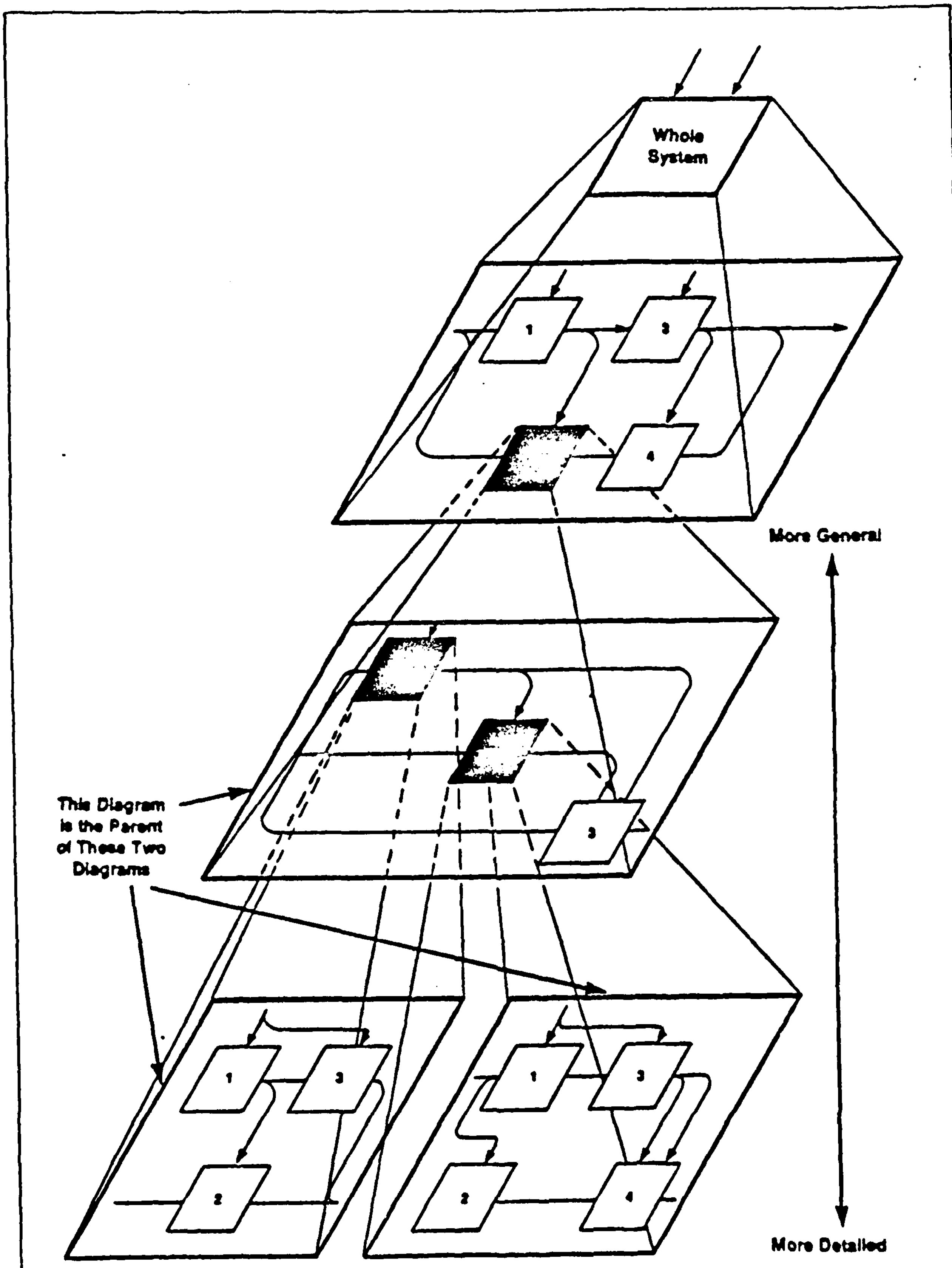


Figure 10. Example of a hierarchical, top-down model.

Diagram node numbers

In an IDEF0 diagram, the component parts are shown as numbered boxes. A diagram should have no more than six boxes. Each box at one level is detailed in one diagram at the next lower level until a sufficient level of detail is reached. The place of each diagram in a model is indicated by a "node number" derived from the numbering of boxes. For example, A21 is the diagram that details box 1 on the A2 diagram. Similarly, A2 details box 2 on the A0 diagram, which is the top diagram of the model. The parent of the A0 diagram represents the system as a single box and is denoted "A-0." The hierarchy may be shown in an index of diagram names and their node numbers called a "node list." The node list serves as a table of contents for a model. In an IDEF0 model, diagrams are displayed in the order of their node numbers.

The example shown in Figure 11 provides an illustration of the hierarchical decomposition of functions. The diagrams in Figure 11 indicate that the overall function, develop system (A0), is broken down into three sub-functions, A1 through A3. Design system (A2) is further broken down into three, more detailed sub-functions (A21 through A23).

Description of Individual IDEF0 Diagrams

In IDEF0, boxes represent components in the breakdown, and arrows represent relationships between these components. Descriptive labels are written inside each box and along each arrow to describe their meaning. The notation is kept simple to permit easy reading with little special training.

Figure 12 shows a sample IDEF0 diagram. Notice that the boxes represent the breakdown of activities or functions performed by the system and are named by verbs. Arrows, which represent objects or information, are labeled with nouns.

Box-and-arrow syntax

The sample IDEF0 diagram in Figure 12 shows that the descriptive names and labels convey the box and arrow contents to the reader. In addition to its label, the side at which an arrow enters or leaves a box shows its role as an input, control, output, or mechanism for the box (see Figure 13). Arrows that enter from the left of an activity box represent inputs to the process represented by the box. Inputs represent the raw materials or data used by the activity to produce outputs. The outputs are represented by arrows that originate from the right side of the box. Arrows entering a box from the top represent controls on the activity. Controls are data that provide catalysts or constraints for the represented activity, but are not changed by the process. Finally, arrows that enter a box from the bottom represent mechanisms. Mechanisms are the agents that perform the activities represented in the box. In short, inputs and outputs represent what is done by the process, controls represent why it is done, and mechanisms represent how it is done.

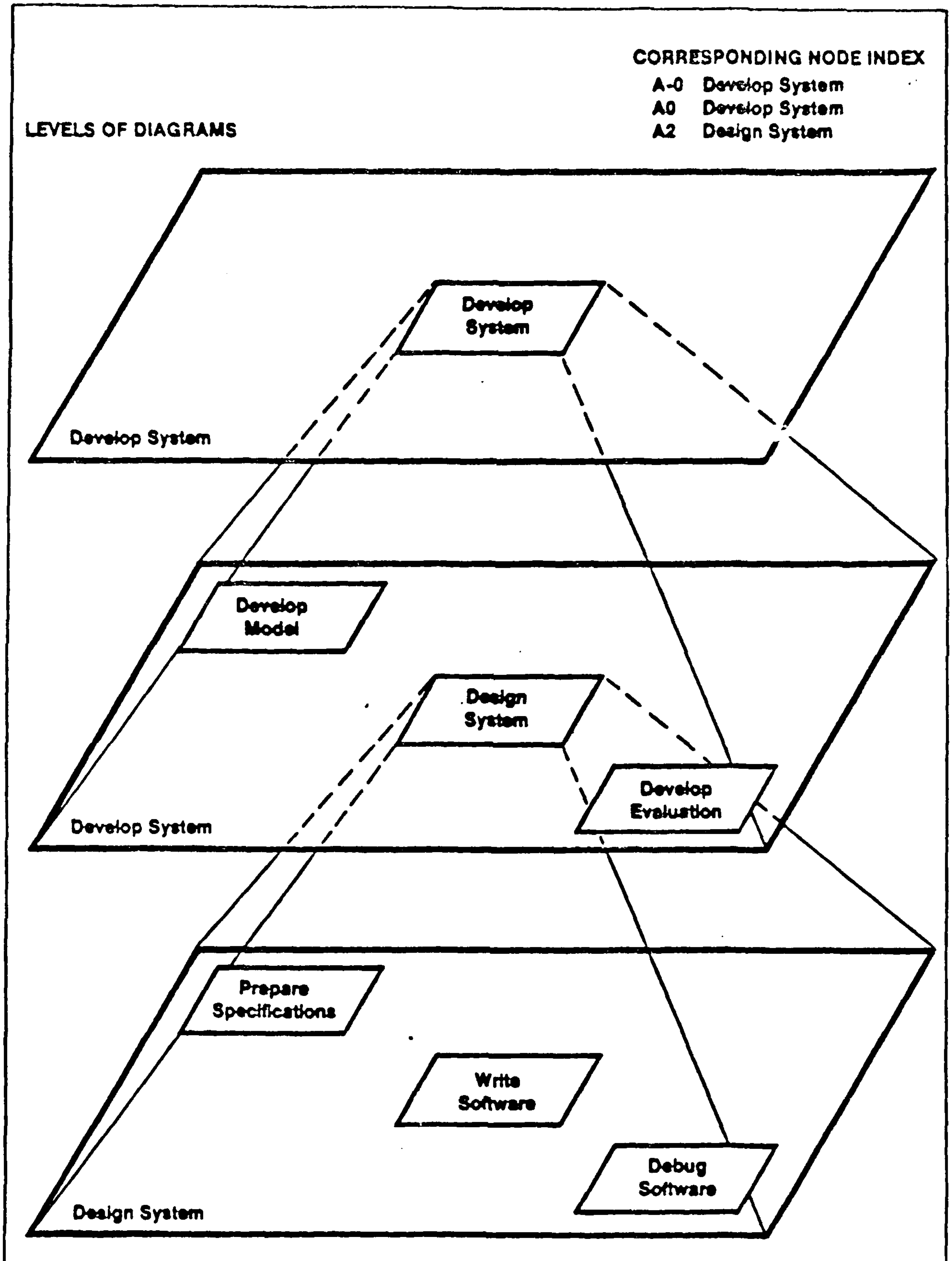


Figure 11. IDEF0 node numbering convention.

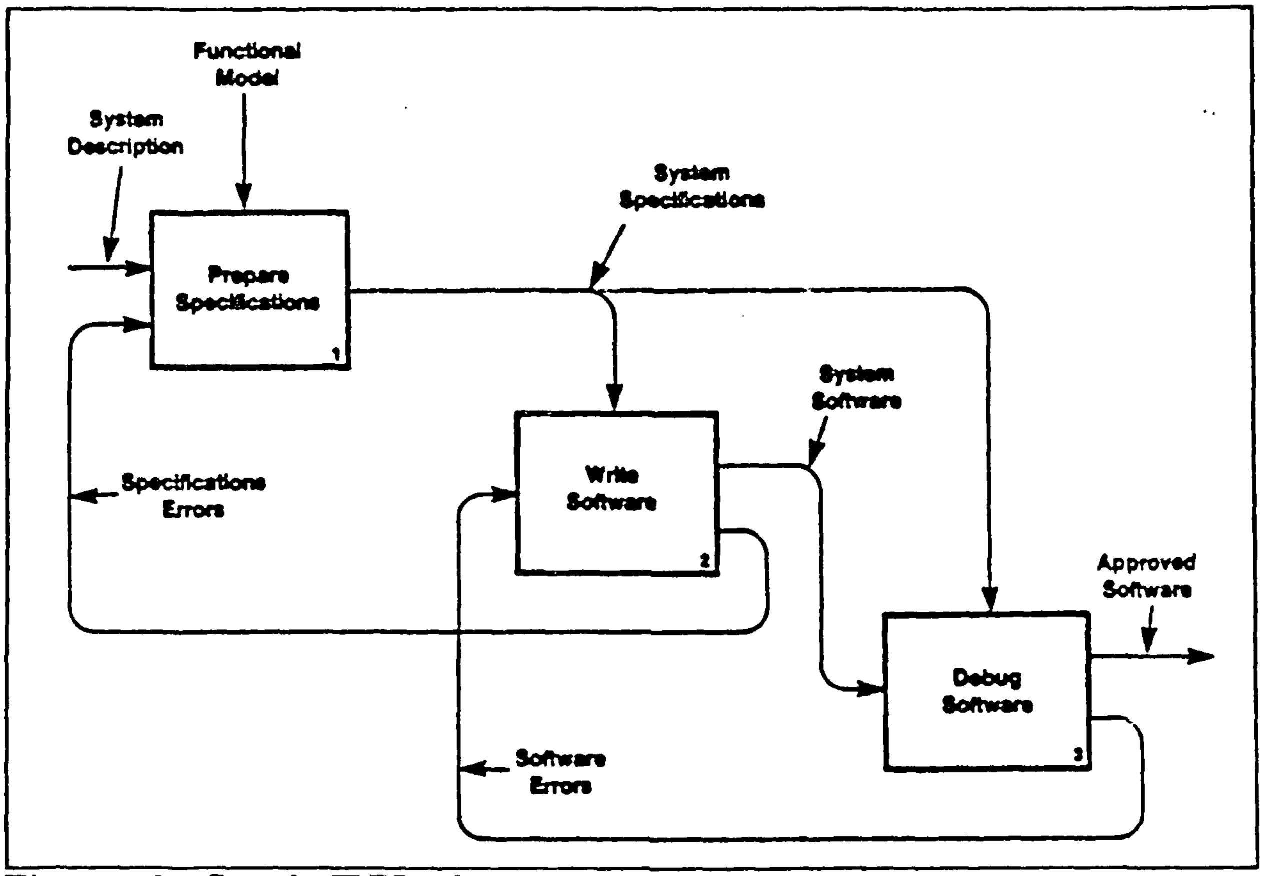


Figure 12. Sample IDEF0 diagram.

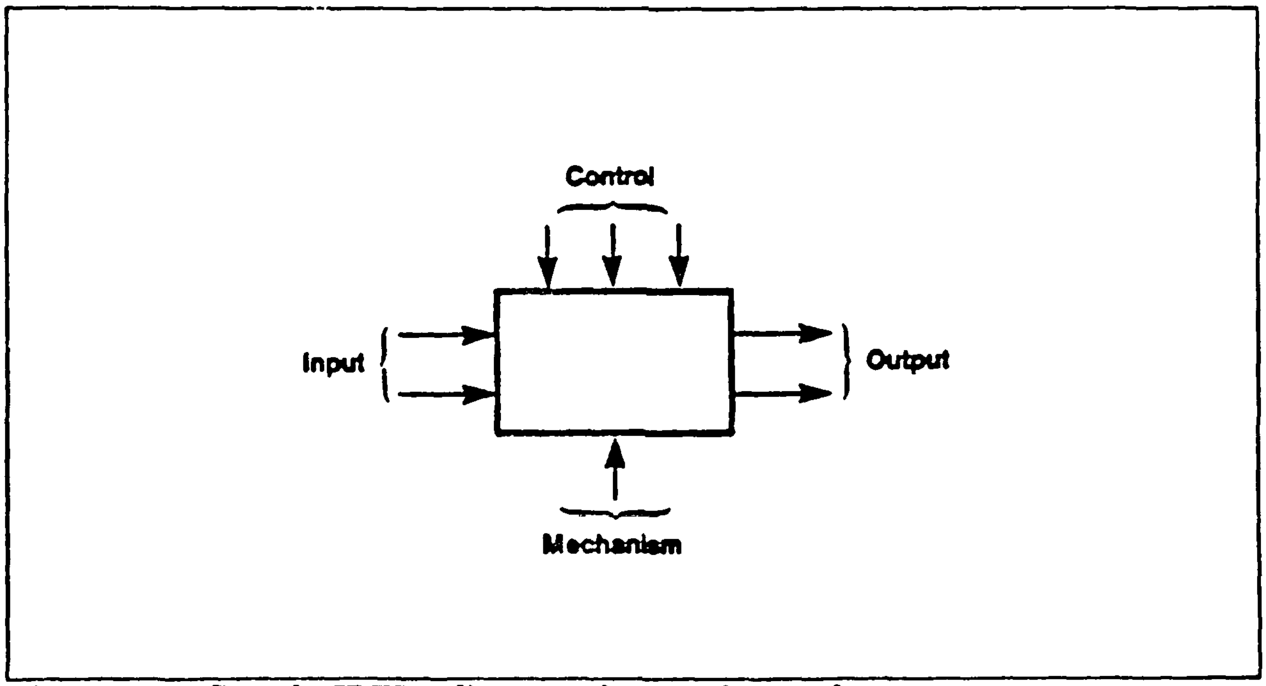


Figure 13. Sample IDEF0 diagram showing box and arrow syntax.

The arrow structure of an IDEF0 diagram represents a constraint relationship among boxes. It does not represent flow of control or sequence. The arrows entering a box show all that is needed by the box to perform its function. Therefore, the box is constrained by its inputs and controls.

Labeling of arrows

Some arrows show both their source and destination boxes on the same diagram, while others have one end unconnected (see Figure 14). The unconnected arrows represent inputs, controls, or outputs of the parent box. To find the source or destination of these unconnected arrows, the reader must locate the matching arrows on the parent diagram. All such unconnected arrows must continue on the parent for the diagrams to be complete.

Although arrow connections from parent boxes to detail diagrams are sometimes obvious from the labels, the IDEF0 methodology includes a special notation to allow readers to do the match quickly. In this notation, unconnected arrows are numbered according to the position of those arrows in the parent diagram. The number of the arrow is preceded by an I, C, O, or M to indicate that it represents an input, control, output, or mechanism in the parent diagram. Thus, if an arrow is labeled "C1," it is the first control listed in the parent diagram. Similarly, an arrow labeled "O3" is the third output in the parent diagram.

It is possible for a data element to serve as an input to some sub-activities of a given activity and as a control for other sub-activities. In this case, the data are represented once in the parent diagram, either as input or control. In the detailed diagrams, the data are represented as a control in some diagrams and as an input in others, as appropriate.

Model Formulation

This section uses IDEF0 to describe the formulation of analysis tools to optimize skill-based training systems. This problem is being approached from the perspective of the training designer. The output of the analysis process is the specification of skill-based training strategies and devices that can meet the training requirements at the lowest cost.

A significant amount of data will be required to operate the models proposed here. Some of these data will be gathered from the research literature and reside in the system's data base. Skill and task analyses will also produce some of the required data. The model users, who are the training developer and subject matter expert, will be required to provide the rest of the data.

In order to facilitate the description the optimization tools fo· skill-based training systems, three tables are included with the IDEF0 diagrams:

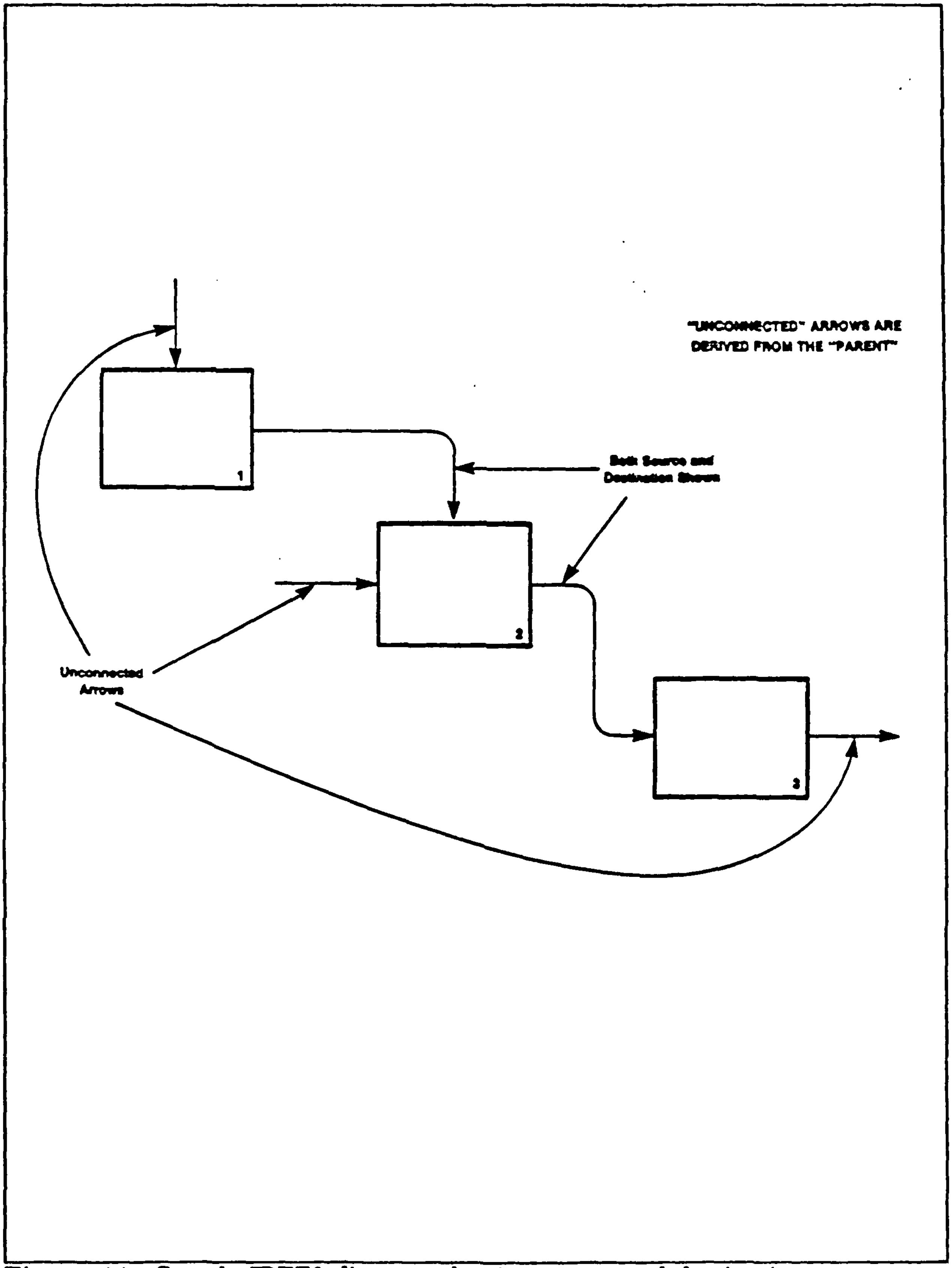


Figure 14. Sample IDEF0 diagram showing source and destination.

1. A list of the nodes in the structure in the order that they appear in the system description. The node list provides the table of contents for the IDEF0 model. If the node is represented by its own diagram, the number of that diagram is listed in the final column of the node list. Nodes that have no detailed diagram do not have a node number listed. The descriptions of such a node may be found on the diagram for its parent node.

2. A list of the model outputs indicating the source node and all destination nodes for each output. A destination listed as "UP" indicates that the output is unconnected in a particular IDEF diagram. The output map specifies whether each output is used as an input or control at the destination node. Each output description is referenced to a single IDEF diagram number as indicated in the output map.

3. A data base map that illustrates all data requirements and mechanisms used by the model. The data base map lists all node numbers in which each data element or mechanism is used, and specifies whether the data are used as an input, control, or mechanism for each node.

A description of a single node in the model consists of three components: two diagrams (which may be repeated) and associated explanatory text. The diagram for the node being described is on the right-hand side of the page; its parent is shown on the left-hand side. The text is written beneath the diagrams. If the explanatory description requires more than two pages, both parent and child diagrams are repeated on the next two pages, until the text is completed.

IDEF Node List

Node	Title	IDEF Number
A-0	Specify Skill-Based Training Strategies and Devices	SB001
A0	Specify Skill-Based Training Strategies and Devices	SB002
A1	Identify Skills for Training	SB003
A11	Select Tasks for Analysis	
A12	Identify Possible General Abilities	SB004
A121	Determine Level of Analysis	
A122	Review Task-Element Verbs	
A123	List Possible Abilities	
A13	Select Required Abilities	SB005
A131	Determine Distinguishing Questions	
A132	Select Abilities Required for Performance	
A133	Verify Performance Gap	
A14	Identify Specific Skills	SB006
A141	Select Skill Frames	
A142	Incorporate Task-Element Objects	
A143	Incorporate Domain Specific Knowledge	
A144	Select Completed Skill Definitions	
A15	Determine Skill Importance	SB007
A151	Calculate Raw Score	
A152	Determine Sum Over Skills	
A153	Divide Raw Score by Sum	
A2	Select Skill-Training Strategies	SB008
A21	Group Skills	SB009
A211	Calculate Object-Set Least Upper Bound	
A212	Partition Skills to Groups	
A213	Calculate Group Weight	
A214	Select Top Skill Groups	
A22	Incorporate Training Criterion	SB010
A221	Determine Maximum Criterion	
A222	Assess Skill Training Factors	
A223	Set Skill Training Criterion	
A23	Incorporate Training Methods	SB011
A231	Select Part or Whole Methods	
A232	Recommend Specific Method	
A24	Determine Interface Requirements	SB012
A241	Select Relevant Interface Dimensions	
A242	Perform Preliminary Restrictions	

IDEF Node List (Cont.)

Node	Title	IDEF Number
A243	Determine Required Levels	
A25	Determine Instructor Support Requirements	
A3	Design Skill-Training Devices	SB013
A31	Organize Skill Groups by Device Requirements	
A32	Select Instructional Features by Device Category	SB014
A321	Calculate Effectiveness Score	
A322	Calculate Feature Benefit	
A323	Compute Benefit/Cost Ratios for Options	
A324	Sort Options by Benefit/Cost Ratios	
A325	List Optimal Features	
A33	Select Interface Features by Device Category	SB015
A331	Construct Training Device Options	
A332	Calculate Cost and Benefit of Options	SB016
A3321	Calculate Costs	
A3322	Determine Skill Trainability	
A3323	Calculate Benefit Scores	
A3324	Calculate Benefit Weights	
A333	Compute Optimal Device Designs	SB017
A3331	Compute Benefit/Cost Ratios for Options	
A3332	Sort Options by Benefit/Cost Ratios	
A3333	Compute Device Designs	
A34	Recommend Device Designs	
A4	Allocate Training	SB018
A41	Detail Skill Interaction with Task Training	SB019
A411	Characterize Baseline Training and Costs	
A412	Characterize Skill Impact on Training	
A42	Determine Per-Student STS/Device Costs	SB020
A421	Determine Skill Learning Curves for Device	
A422	Determine Required STS Training Time by Device	
A423	Determine Per-Student Cost by STS/Device	
A43	Determine Impact on Task Training Costs	SB021
A431	Determine Training Cost without STS/Device	
A432	Determine Training Cost with STS/Device	
A433	Determine Training Cost Savings with STS/Device	
A44	Choose Next STS/Device for Greatest Payoff	SB022
A441	Construct Payoff Matrix	
A442	Determine Payoff for Each STS/Device	
A443	Select STS/Device with Greatest Payoff	

IDEF Output Map

Description	Source	Destination	Function	IDEF Number
Specific Skills	A1	UP		SB002
Specific Skills	A1	A2	Input	SB002
Specific Skills:				
Specific Skills	A14	UP		SB003
Specific Skills	A14	A15	Input	SB003
Specific Skills	A144	UP		SB006
Skill Importance Weight	A15	UP		SB003
Skill Importance Weight	A153	UP		SB007
Selected Tasks:				
Task Element Verbs	A11	A12	Input	SB003
Task Element Objects	A11	A13	Control	SB003
Task Element Objects	A11	A14	Control	SB003
Training Time & Criticality	A11	A15	Control	SB003
Possible General Abilities	A12	A13	Input	SB003
Possible General Abilities	A123	UP		SB004
General Abilities Required For Training	A13	A14	Input	SB003
General Abilities Required For Training	A133	UP		SB005
Selected Task-Element Verbs	A121	A122	Input	SB004
Revised Task-Element Verbs	A122	A123	Control	SB004
Distinguishing Features	A131	A132	Control	SB005
Abilities Required for Performance	A132	A133	Input	SB005
Selected Skill Frames	A141	A142	Input	SB006
Partial Skill Definitions	A142	A143	Input	SB006
Elaborated Skill Definitions	A143	A144	Input	SB006
Raw Skill Importance	A151	A152	Input	SB007
Raw Skill Importance	A151	A153	Input	SB007
Normalization Factor	A152	A153	Input	SB007
Device Requirements	A2	A3	Control	SB002
Device Requirements:				
Interface Requirements	A24	UP		SB008
Interface Requirements	A243	UP		SB012
Instructor Support Requirements	A25	UP		SB008
Training Strategies	A2	UP		SB002
Training Strategies	A2	A3	Input	SB002
Training Strategies	A2	A4	Input	SB002
Training Strategies	A23	UP		SB008

IDEF Output Map (Cont.)

Description	Source	Destin-ation	Function	IDEF Number
Training Strategies	A23	A24	Control	SB008
Training Strategies	A23	A25	Control	SB008
Training Strategies	A232	UP		SB011
Selected Skill Groups	A21	A22	Input	SB008
Selected Skill Groups	A214	UP		SB009
Partial Training Strategies	A22	A23	Input	SB008
Partial Training Strategies	A223	UP		SB010
Least Upper Bounds	A211	A212	Control	SB009
Skill Groups	A212	A213	Input	SB009
Skill Groups	A212	A214	Input	SB009
Skill Group Weights	A213	A214	Control	SB009
Maximum Criterion	A221	A223	Control	SB010
Skill Training Advantage	A222	A223	Control	SB010
Whole-Part Recommendations	A231	A232	Input	SB011
Relevant Dimensions	A241	A242	Input	SB012
Relevant Dimensions	A241	A243	Input	SB012
Level Restrictions	A242	A243	Input	SB012
Training Device Designs	A3	UP		SB002
Training Device Designs	A3	A4	Input	SB002
Training Device Designs	A34	UP		SB013
Skill/Device Matrix	A31	A32	Input	SB013
Skill/Device Matrix	A31	A33	Input	SB013
Skill/Device Matrix	A31	A34	Input	SB013
Selected Instructional Features	A32	A34	Input	SB013
Selected Instructional Features	A325	UP		SB014
Selected Interface Features	A33	A34	Input	SB013
Selected Interface Features	A333	UP		SB015
Selected Interface Features	A3333	UP		SB017
Weighted Feature Effectiveness	A321	A322	Input	SB014
Feature Benefit	A322	A323	Input	SB014
Benefit/Cost Ratio	A323	A324	Control	SB014
Benefit/Cost Priority	A324	A325	Control	SB014
Training Device Options	A331	A332	Input	SB015
Training Device Options	A331	A333	Input	SB015
Cost and Benefit of Options	A332	A333	Control	SB015
Cost and Benefit of Options:				
Option Costs	A3321	UP		SB016
Option Benefit Scores	A3323	UP		SB016
Option Benefit Scores	A3323	A3324	Input	SB016

IDEF Output Map (Cont.)

Description	Source	Destin-ation	Function	IDEF Number
Fidelity Dimension Weights	A3324	UP		SB016
Skills Trained by Option	A3322	A3323	Input	SB016
Benefit/Cost Ratio for Options	A3331	A3332	Control	SB017
Benefit/Cost Priority of Options	A3332	A3333	Control	SB017
Training Allocation	A4	UP		SB002
Training Allocation	A4	A3	Control	SB002
Training Allocation: Selected Strategies/Devices	A44	UP		SB018
Selected Strategy/Device	A443	UP		SB022
Skill Impact Parameter Values	A41	A43	Control	SB018
Skill Impact Parameter Values	A412	UP		SB019
Baseline Training Cost	A41	A43	Control	SB018
Baseline Training Cost	A411	UP		SB019
Skill Levels Achieved	A42	A43	Input	SB018
Skill Levels Achieved	A42	A44	Input	SB018
Skill Levels Achieved	A424	UP		SB020
Strategy/Device Cost	A42	A44	Input	SB018
Strategy/Device Cost	A423	UP		SB020
Per-Student Cost Savings	A43	A44	Control	SB018
Per-Student Cost Savings	A433	UP		SB021
Pre-Task Training Skill Levels	A44	A42	Control	SB018
Pre-Task Training Skill Levels	A44	A43	Control	SB018
Pre-Task Training Skill Levels	A443	UP		SB022
Revised Baseline Training Cost	A44	A43	Control	SB018
Revised Baseline Training Cost	A443	UP		SB022
Baseline Task Training Description	A411	A412	Input	SB019
Skill Learning Curves by Strategy/Device	A421	A422	Input	SB020
Training Times by Strategy/ Device	A422	A423	Input	SB020
Cost without Strategy/Device	A431	A433	Input	SB021
Cost with Strategy/Device	A432	A433	Input	SB021
Skill Training Payoff Matrix	A441	A442	Input	SB022
STS/Device Payoffs	A442	A443	Input	SB022

Data Base Map

Description	Destination	Function	IDEF Number
Task Data	A0	Input	SB001
	A1	Input	SB002
	A2	Input	SB002
	A4	Input	SB002
	A11	Input	SB003
Task Training Criteria	A22	Control	SB008
	A221	Control	SB010
Task Training Device Fidelities and Instructional Features	A41	Input	SB018
	A411	Input	SB019
Task Training Sequence	A41	Input	SB018
	A411	Input	SB019
Skill List (Skill Data)	A0	Input	SB001
	A1	Input	SB002
General Ability List	A12	Input	SB003
	A123	Input	SB004
Device Design Options	A0	Input	SB001
	A2	Input	SB002
	A3	Input	SB002
Interface Options	A24	Input	SB008
	A241	Input	SB012
	A33	Input	SB013
	A331	Input	SB015
Instructor Support Options	A25	Input	SB008
	A32	Input	SB013
	A321	Input	SB014
	A324	Input	SB014
	A325	Input	SB014
Benefit Weight	A322	Input	SB014
Instructional Feature Cost	A323	Input	SB014

Data Base Map (cont.)

Description	Destination	Function	IDEF Number
Task Training Device Cost Data	A411	Input	SB019
	A412	Input	SB019
Semantic Information	A0	Control	SB001
	A1	Control	SB002
Verb Hierarchy	A12	Control	SB003
	A121	Control	SB004
	A122	Control	SB004
Verb-Ability Associations	A12	Control	SB003
	A122	Control	SB004
	A123	Control	SB004
Learner Characteristics	A0	Control	SB001
	A1	Control	SB002
	A2	Control	SB002
	A4	Control	SB002
	A11	Control	SB003
	A41	Control	SB018
	A42	Control	SB018
	A412	Control	SB019
Entry Skill Level	A13	Control	SB003
	A133	Control	SB005
	A23	Control	SB008
	A231	Control	SB011
	A421	Control	SB020
Number of Students Annually	A423	Control	SB020
Domain Information	A0	Control	SB001
	A1	Control	SB002
	A2	Control	SB002
	A3	Control	SB002
	A13	Control	SB003
	A14	Control	SB003
	A132	Control	SB005
	A143	Control	SB006
	A21	Control	SB008
	A24	Control	SB008

Data Base Map (cont.)

Description	Destination	Function	IDEF Number
Domain Information (cont.)	A25	Control	SB008
	A242	Control	SB012
	A243	Control	SB012
Object Hierarchy	A211	Control	SB009
Training Device Information	A31	Control	SB013
	A32	Control	SB013
	A33	Control	SB013
	A321	Control	SB014
	A331	Control	SB015
Resource Constraints	A0	Control	SB001
	A3	Control	SB002
	A34	Control	SB013
Completion Criteria	A144	Control	SB006
User-Selected Number of Groups	A214	Control	SB009
Skill Impact Evaluation Framework	A41	Control	SB018
	A43	Control	SB018
	A412	Control	SB019
	A432	Control	SB021
Training Designer	A0	Mechanism	SB001
	A1	Mechanism	SB002
	A2	Mechanism	SB002
	A3	Mechanism	SB002
	A11	Mechanism	SB003
	A12	Mechanism	SB003
	A121	Mechanism	SB004
	A122	Mechanism	SB004
	A21	Mechanism	SB008
	A214	Mechanism	SB009
	A32	Mechanism	SB013
	A33	Mechanism	SB013
	A34	Mechanism	SB013
	A325	Mechanism	SB014
	A331	Mechanism	SB015
	A333	Mechanism	SB015

Data Base Map (cont.)

Description	Destination	Function	IDEF Number
Training Designer (cont.)	A3333	Mechanism	SB017
SME	A0	Mechanism	SB001
	A1	Mechanism	SB002
	A2	Mechanism	SB002
	A4	Mechanism	SB002
	A12	Mechanism	SB003
	A13	Mechanism	SB003
	A14	Mechanism	SB003
	A122	Mechanism	SB004
	A132	Mechanism	SB005
	A133	Mechanism	SB005
	A143	Mechanism	SB006
	A22	Mechanism	SB008
	A23	Mechanism	SB008
	A24	Mechanism	SB008
	A25	Mechanism	SB008
	A221	Mechanism	SB010
	A222	Mechanism	SB010
	A231	Mechanism	SB011
	A232	Mechanism	SB011
	A243	Mechanism	SB012
	A41	Mechanism	SB018
	A411	Mechanism	SB019
	A421	Mechanism	SB020
Optimization Methods	A0	Mechanism	SB001
OSBATS Methodology	A4	Mechanism	SB002
	A41	Mechanism	SB018
	A42	Mechanism	SB018
OSBATS Learning Curve Construction Methodology	A411	Mechanism	SB019
	A421	Mechanism	SB020
OSBATS Training Device Selection Methodology	A412	Mechanism	SB019
OSBATS Device Costing Methodology	A423	Mechanism	SB020

System Description

SB/A-0: Specify Skill-Based Training Strategies and Devices

The purpose of the Skill-Based Optimization of Training model is to specify the skill-training strategies and devices that meet training requirements at the lowest cost. Training effectiveness is measured by the level of performance on designated tasks. Cost has investment, fixed operating and variable operating components.

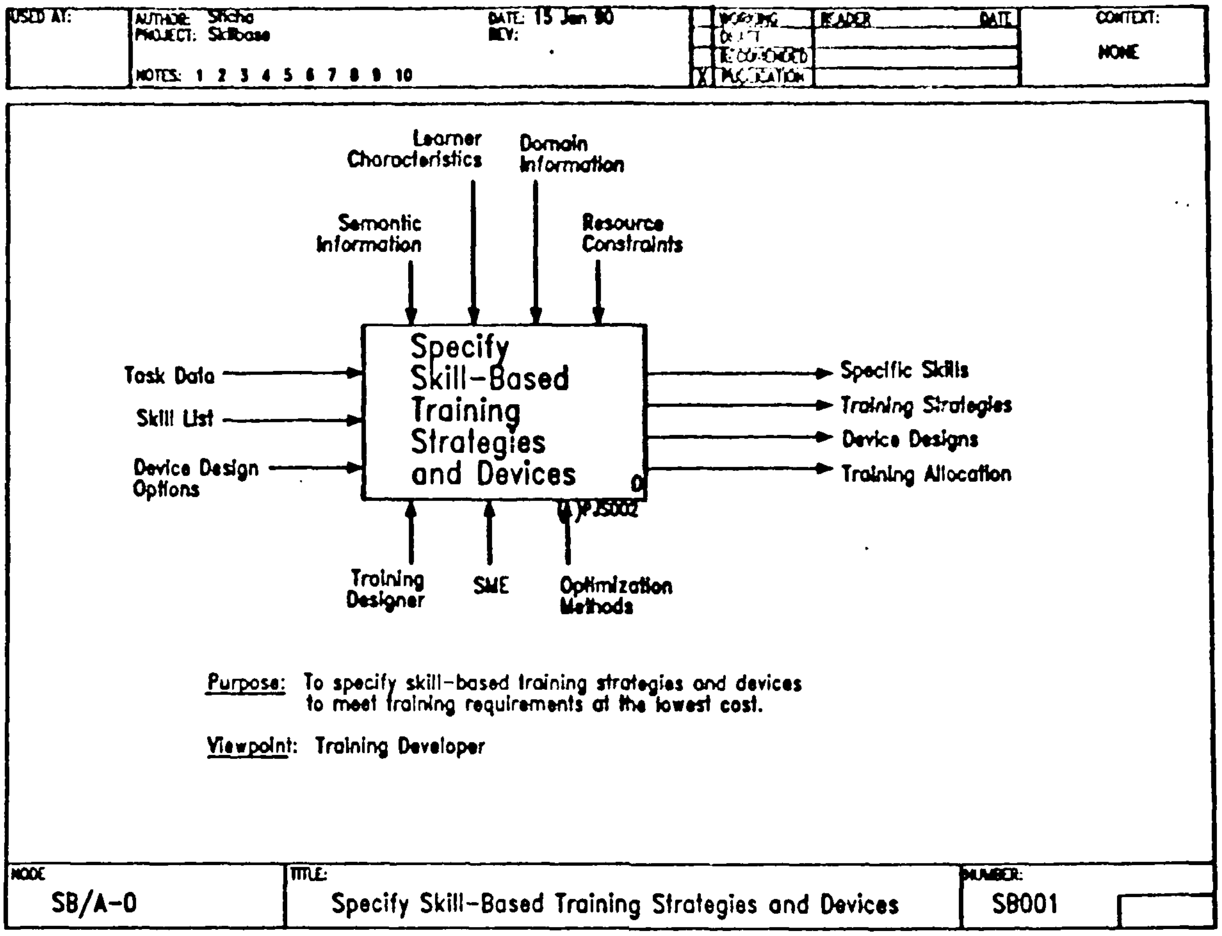
This analysis breaks the specification of skill-based training strategies and devices into four steps and describes the processes that comprise these steps. The IDEF0 diagrams describe the solution process from the perspective of the training designer.

The IDEF0 analysis assumes that training requirements are defined by a set of tasks that must be performed to prescribed standards at the conclusion of the training period. First, the specific skills required to meet task performance criteria are identified. Next, skill-training strategies are developed for each skill. Then skill training devices are designed to implement each strategy. Finally a cost-benefit analysis is conducted to identify which skill training strategies and devices lower the cost of training from that established by a solution (i.e., OSBATS) that is purely oriented to task training.

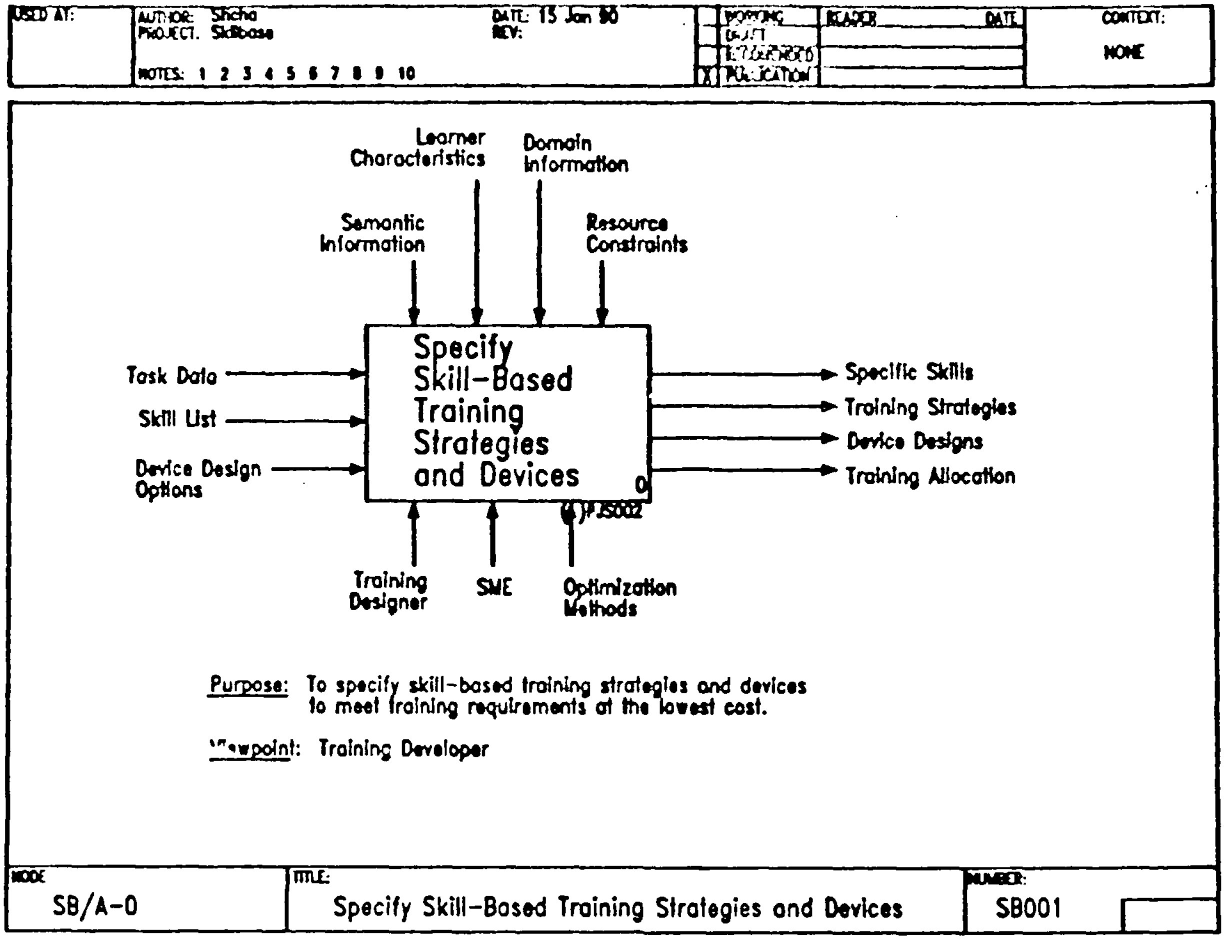
Input Data. Input data consist of the task data, skill data, and training device options (including instructional features and interface elements). Task data include information typically produced by a task analysis, including descriptions of tasks, subtasks, and task elements, as well as ratings of task criticality, frequency of performance, and required training time. Skill data include a list of general abilities, skill definitions used to distinguish different abilities, and frameworks for building specific skills from general abilities. Device design options include cost and performance information about the interface and instructional components that could form the components of a skill-based training device.

Controls. Three types of data control the solution process: resource constraints, learner characteristics, and domain information. Resource constraints specify the amount of money available for training-device development or the per-student life cycle cost constraint for training. Learner characteristics establish the entry-level skills and task performance levels of the students. Domain information describes characteristics of the job being trained, such as equipment used, displays and controls, and specific features of job performance.

Mechanisms. Mechanisms employed in this solution process are the users of the model and optimization methods. We distinguish two user roles, training designer and subject-matter expert. Optimization methods are employed by all subactivities; consequently, this mechanism will not be shown in the descriptions of lower-level activities.



Output. The primary output of this process is an allocation of training time to skills and tasks on the relevant devices for each. This allocation of training achieves a lower cost than would be obtained by training tasks alone. Other outputs include the skills that need to be trained, the training strategy for each skill, and a definition of the training device that is used to implement each skill-based training strategy.

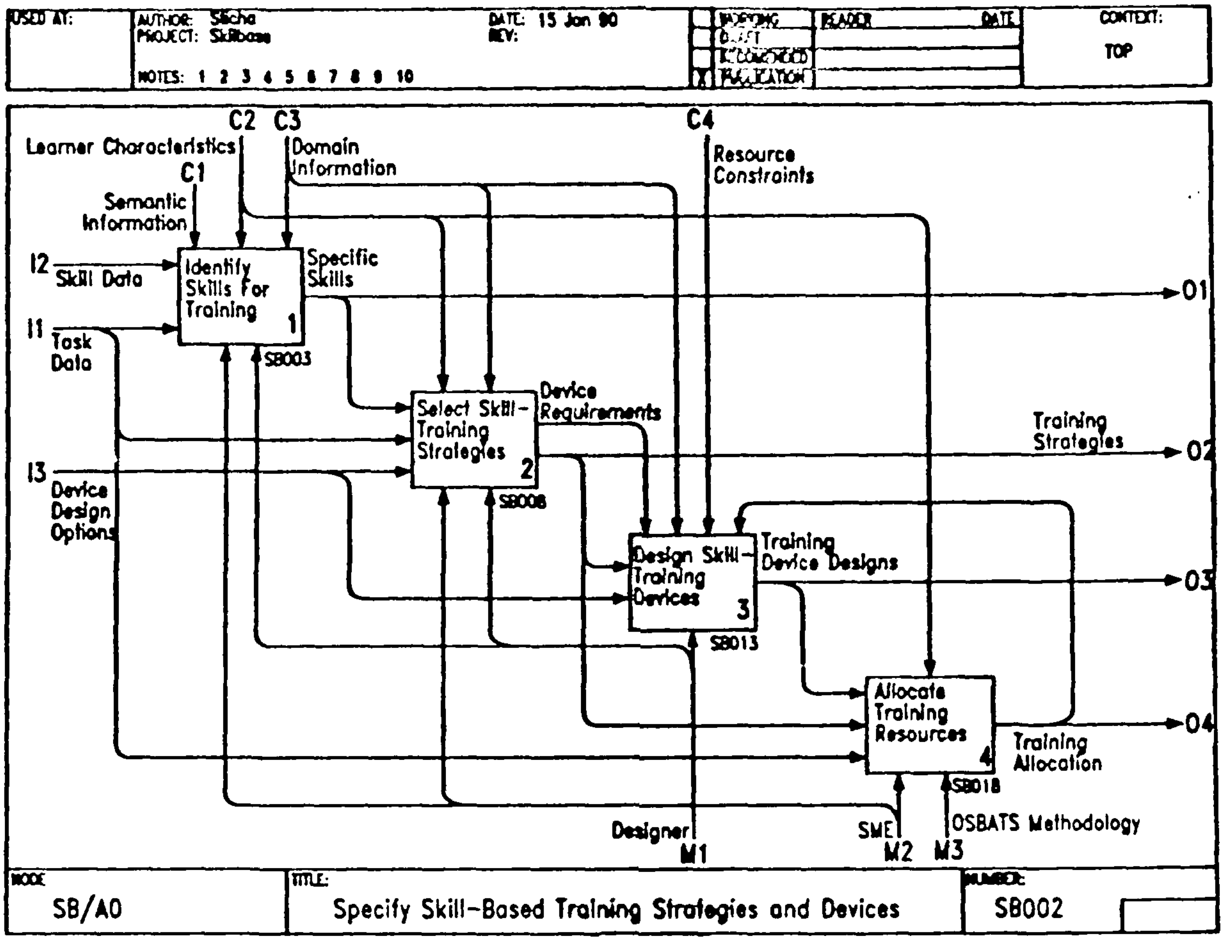


SB/A0: Specify Skill-Based Training Strategies and Devices

This overall model process consists of four major activities: (a) identifying the specific skills required for job performance, (b) organizing skills to determine training strategies, (c) designing training devices to implement the skill-training strategies, and (d) allocating training time to skill and task training to minimize the training cost needed to achieve the required task performance.

SB/A1: Identify skills for training. This activity identifies the specific skills needed to achieve training requirements. First, the tasks that offer the greatest potential for skill training are identified. Then general abilities are matched to task activities, and the required abilities are identified. The general abilities are defined in greater detail to produce specific skills. Finally, the relative importance of the specific skills for training each task are determined.

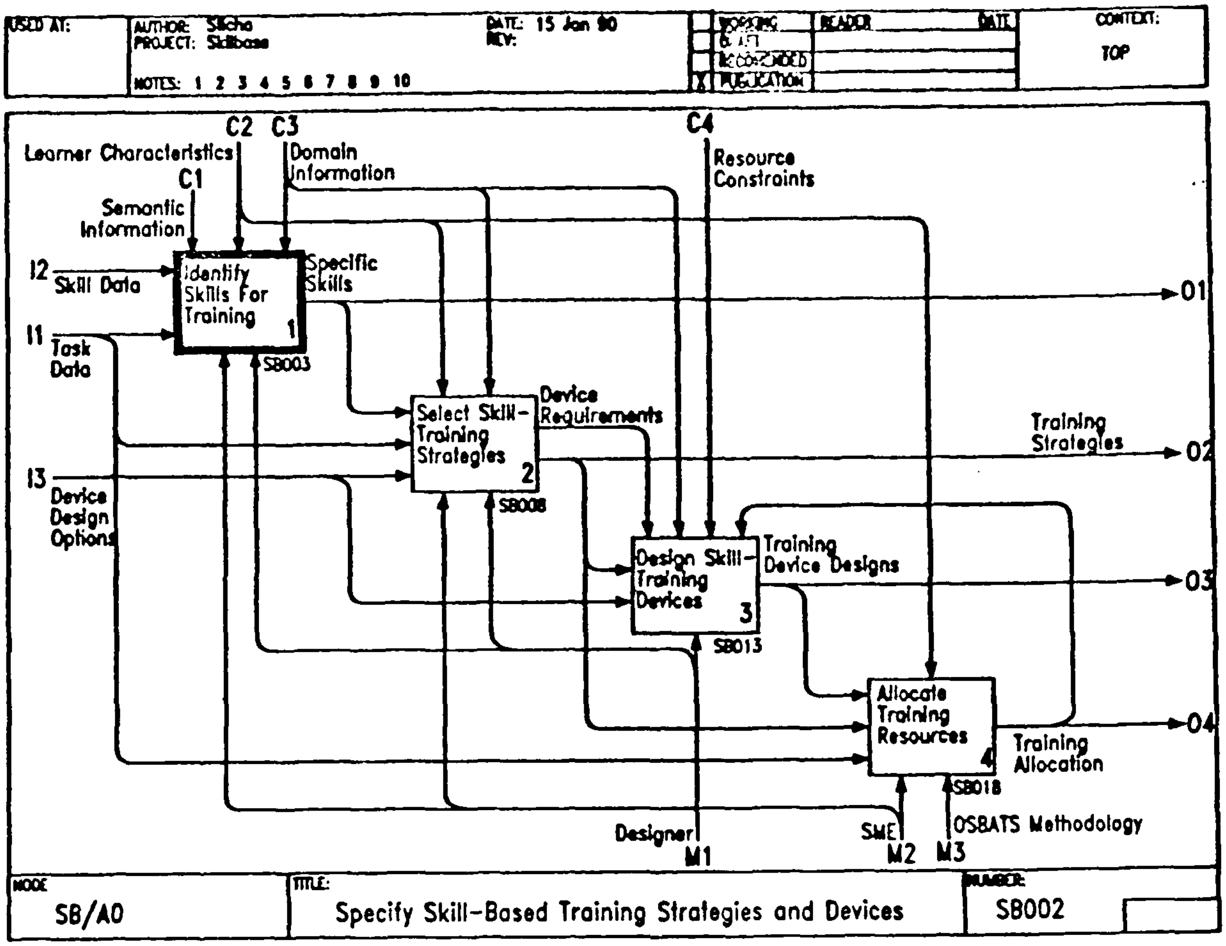
SB/A2: Select skill-training strategies. This activity defines skill-training strategies (STSs), which consist of a group of skills to be trained, a training criterion, and a sequencing method. In addition, the activity defines interface and instructor support requirements for each skill-training strategy. Skills are grouped according to the to objects on which they operate and according to the general ability category required. The skill training criterion incorporates information about relevant task training criteria, as well as characteristics of the



skill. The sequencing options are recommended based upon the entry skill level, and particular sources of difficulty in skill performance. The training strategy controls the selection of interface and instructor support requirements.

SB/A3: Design Devices. This activity applies a cost-benefit analysis to specify the interface levels and instructional features that provide the maximum enhancement per development dollar. The activity is applied individually for each class of skill-training device being designed. In this activity, skill-training strategies are initially organized according to their device requirements. Optimal instructional features and interface levels are then determined using a cost-benefit analysis. The recommendations regarding instructional features and interface levels are then combined to recommend a skill-training device design.

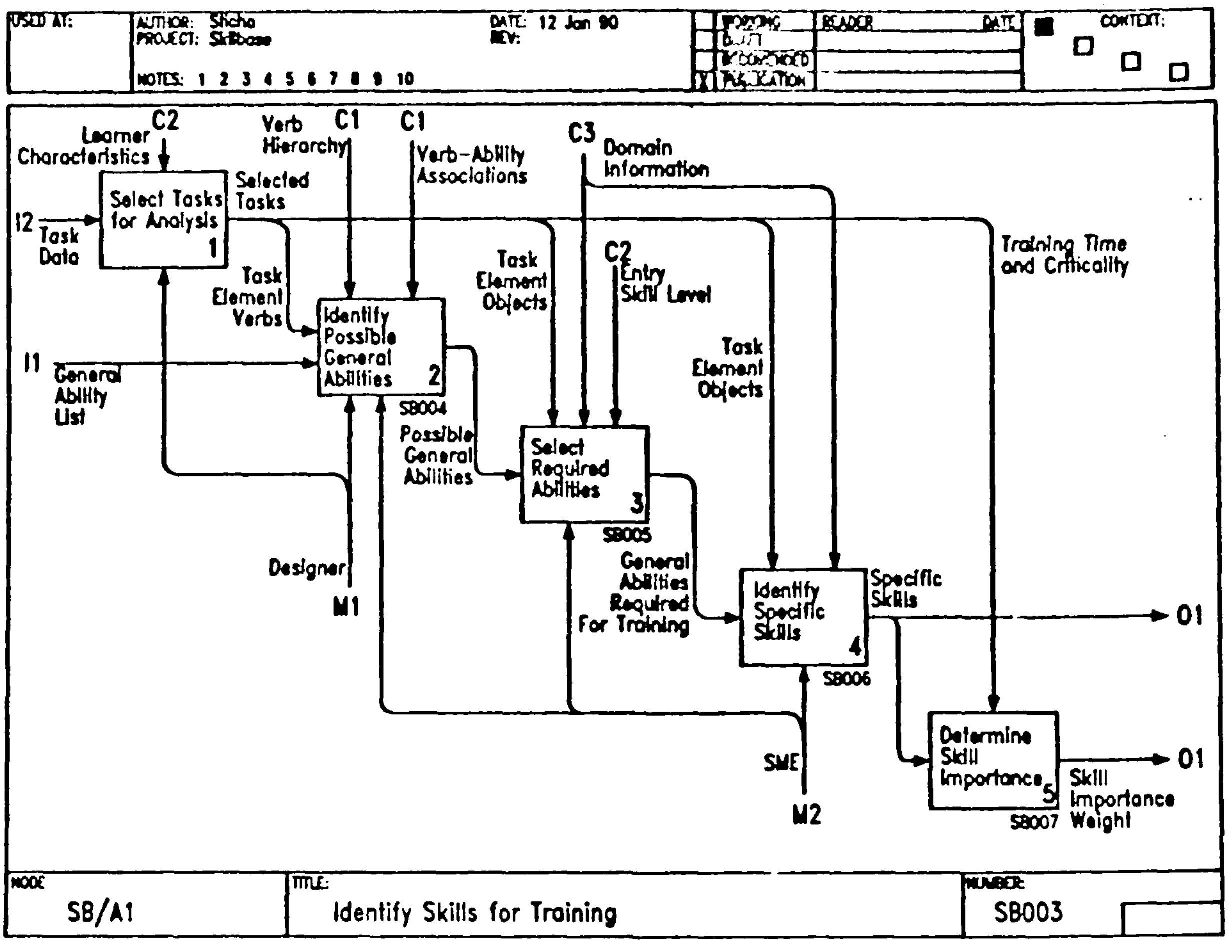
SB/A4: Allocate Training. This activity uses cost-benefit optimization to find the lowest training cost using a combination of skill and task training. The skill-training strategies and their devices are first ordered according to their cost-effectiveness. Then the list is searched to find the break even point where additional skill training is no longer cost-effective compared to task training.



SB/A1: Identify Skills for Training

This activity produces a list of specific skills required to achieve training requirements defined by a set of tasks with standards, given the entry level performance capabilities of the student population, information about the job domain, and knowledge of the procedures that were used to describe tasks and their components. After those tasks for which skill training is not applicable are eliminated, general abilities are associated with each remaining task. Each general ability identified is then defined in terms of the specific actions and objects of these actions by which the ability is instantiated. Finally the relative importance of the specific skills for training each task is determined.

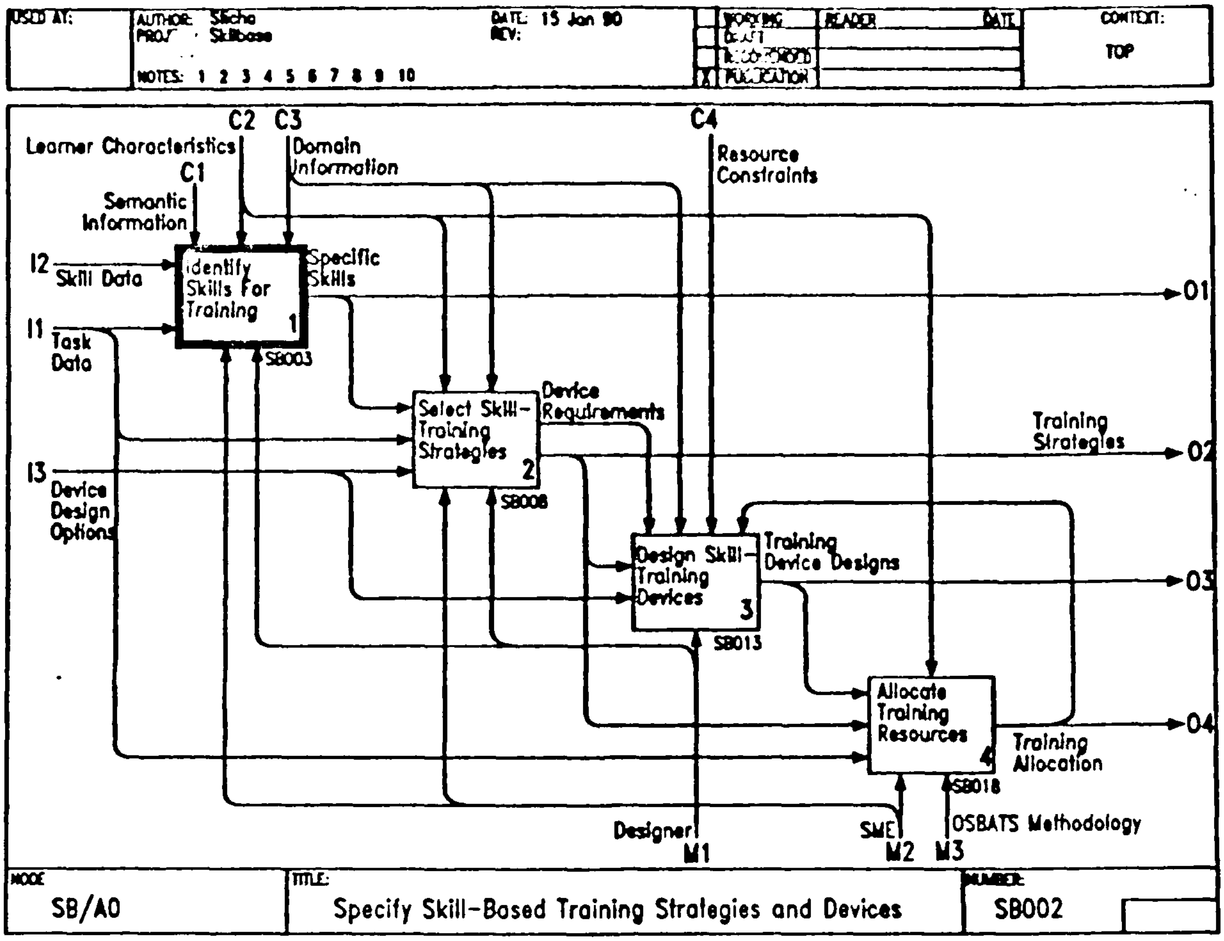
SB/A11: Select tasks for analysis. This activity examines the tasks composing the training requirement to select those tasks for which skill-based training is appropriate. Factors examined include: (a) entry level performance—skill training is most effective if the students entry performance level is low; (b) total task training time on the actual equipment—if a task requires a great deal of training, there is a large potential for benefits from skill training; and (c) workload—if the task workload is great (e.g., the task requires time sharing among multiple activities), then skill training may reduce the workload during training. The data required for this activity are assumed to be available from existing task analyses. This activity will assess the values of relevant data



variables, calculate a weighted sum of the multiple variables to produce a single index, and select those tasks for which the index is greater than a designer-specified criterion value. The output is a list of tasks that are suited for skill training.

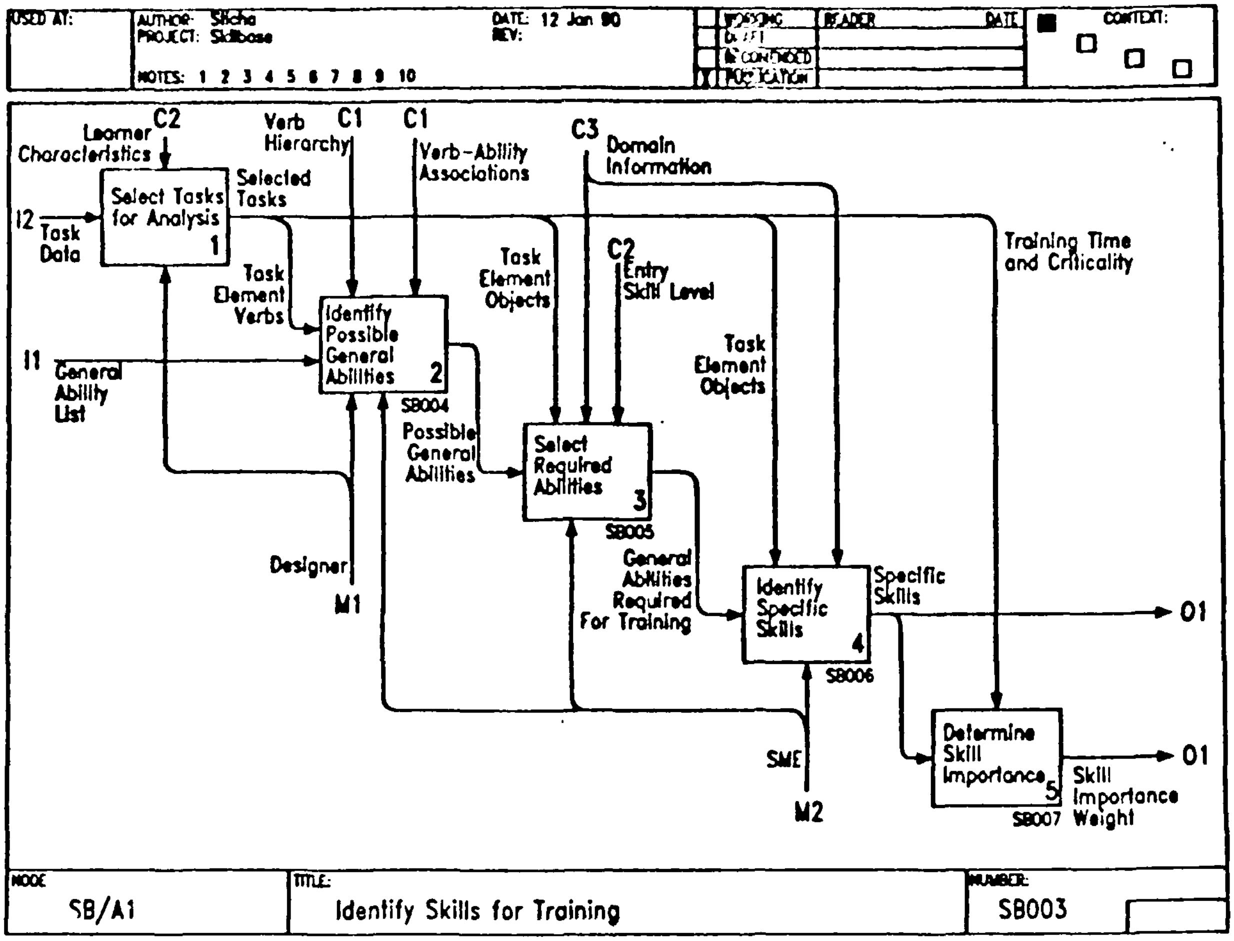
SB/A12: Identify possible general abilities. This activity identifies a set of general abilities that includes the abilities actually involved in performing the tasks. The abilities are chosen from a list of general abilities based on the description of the action involved in each task element. The selection of abilities is based on associations that tie each verb in a task element description to one or more general abilities. In general, this activity will generate more general abilities than are actually required by the tasks. Irrelevant abilities are eliminated in the next two processes.

SB/A13: Select required abilities. This activity selects the general abilities that are required for training from the candidate abilities identified in the previous process. The selection is based on the objects the task-element actions, and knowledge about the job domain. Some of the required job knowledge will be provided by a subject-matter expert (SME), such as an instructor or job incumbent. The abilities required for training will be those selected general abilities with sufficiently low entry skill level.

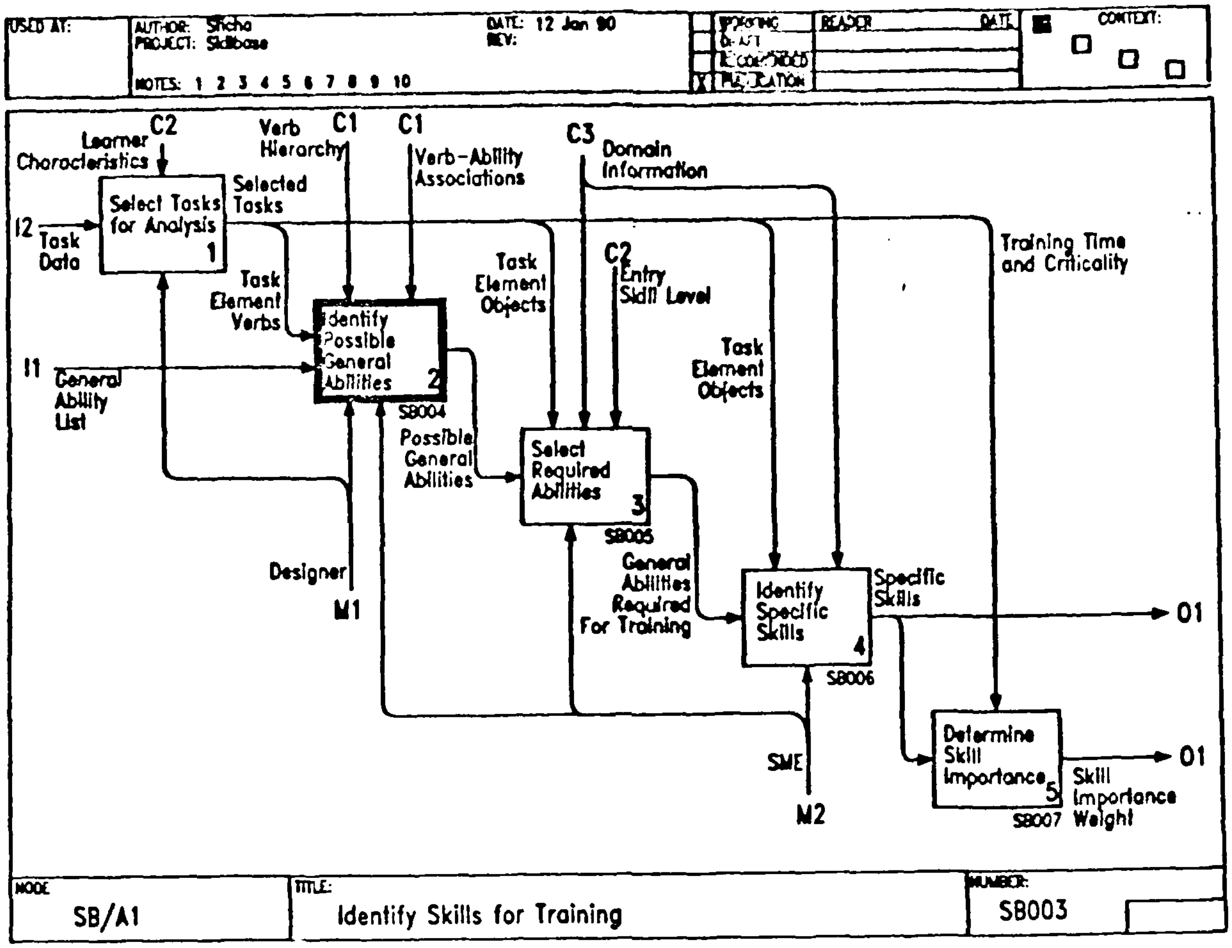


SB/A14: Identify specific skills. This activity adds detail to the general abilities that were identified in the previous activity to produce a description of the specific skills required for training. The type of general ability (e.g., pattern recognition) determines what kind of information is required to produce a specific skill description (e.g., the sensory modality, the pattern that must be recognized, the background in which the pattern is located, a description of conditions, etc.). The required information may come from the objects of the task-element actions, or domain information. Some of the required job knowledge will be provided by SMEs. The output of this activity is a set of definitions of the specific skills required for job performance.

SB/A15: Determine skill importance. The previous activities have defined and refined a matrix that relates skills to those tasks that can be reasonably trained to higher performance levels through skill training. This activity assigns relative importance across the skills for enhancing the performance of a particular task. The importance weight will be based on the results of a task analysis: task training time, task criticality, and task-element criticality. The output of this activity is a set of weights that express the relative importance of each skill identified in the analysis.



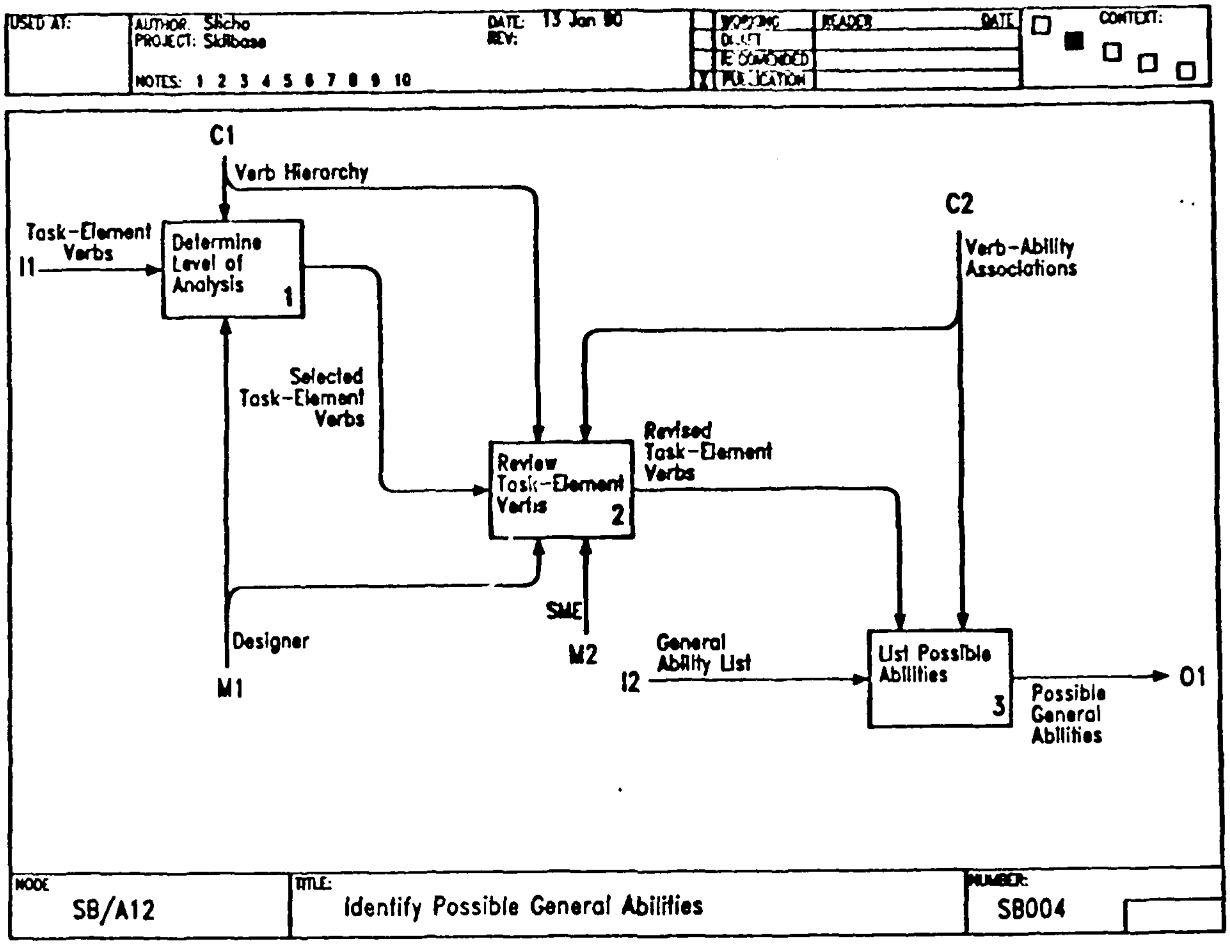
USED AT:
AUTHOR: Slicha
PROJECT: Skillbase
DATE: 12 Jan 90
REV:
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C2
Learner Characteristics
Verb Hierarchy
C1
C1
Verb-Ability Associations
C3
Domain Information
I2
Task Data
Select Tasks for Analysis
1
Selected Tasks
Training Time and Criticality
Task Element Verbs
Task Element Objects
C2
Entry Skill Level
Identify Possible General Abilities
2
SB004
I1
General Ability List
Task Element Objects
Possible General Abilities
Select Required Abilities
3
SB005
Designer
M1
General Abilities Required For Training
Identify Specific Skills
4
SB006
Specific Skills
O1
SME
M2
Determine Skill Importance
5
SB007
O1
Skill Importance Weight
NODE: SB/A1
TITLE: Identify Skills for Training
NUMBER: SB003



SB/A12: Identify Possible General Abilities

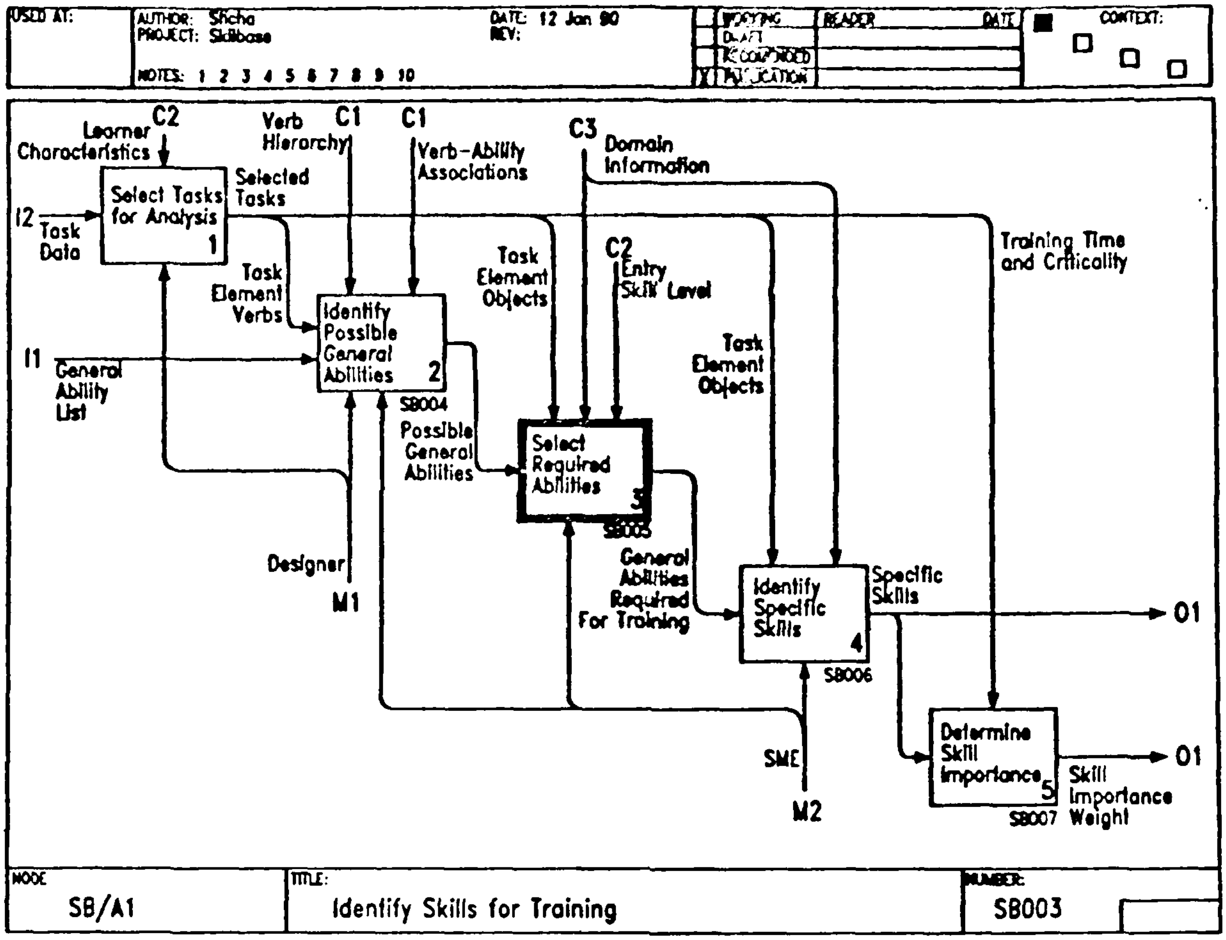
This activity lists general abilities that may be involved in a job, based on a description of task-element actions that is part of a task analysis. The first two steps in this activity review the task analysis to ensure a consistent and appropriate level of detail in the verbs used to describe task-element actions.

SB/A121: Determine level of analysis. Task analyses divide tasks into subtasks and task elements. This activity examines the subtask and task-element descriptions and compares the verbs used in these descriptions to an internal verb hierarchy. The verbs used to describe subtasks and task elements will have an influence on the output of this activity. The verbs should be as specific as possible; that is, they should be associated with as few skills as possible. When a subtask verb is at the lowest level of the verb hierarchy, then the system recommends analysis at the subtask level. The system also recommends analysis at the subtask level when the subtask is procedural. When the subtask verb is at an intermediate level of the verb hierarchy, and the related task-element verbs are at lower level, then the system will recommend analysis at the task-element level for the elements of that subtask. The system will present the recommendations to the training designer, who will either accept or overrule them.



SB/A122: Review task-element verbs. This step reviews the subtask or task-element statements that are generated in the previous step. If the verbs are not at the lowest level of the verb hierarchy and the verbs are associated with more than one general ability on the internal verb-by-ability association matrix, then the SME is prompted to provide a more specific description of the task element. For example, the verb "synthesize" may require any of several skills. If this verb were used to characterize a task element, the SME would be prompted to give a more precise description of the action, such as "integrate." This step is conducted to minimize the number of possible general abilities that are generated in the next step of the analysis.

SB/A123: List possible general abilities. This step lists the possible general abilities, based on a verb-by-ability matrix that associates each available task-element verb with one or more general abilities.

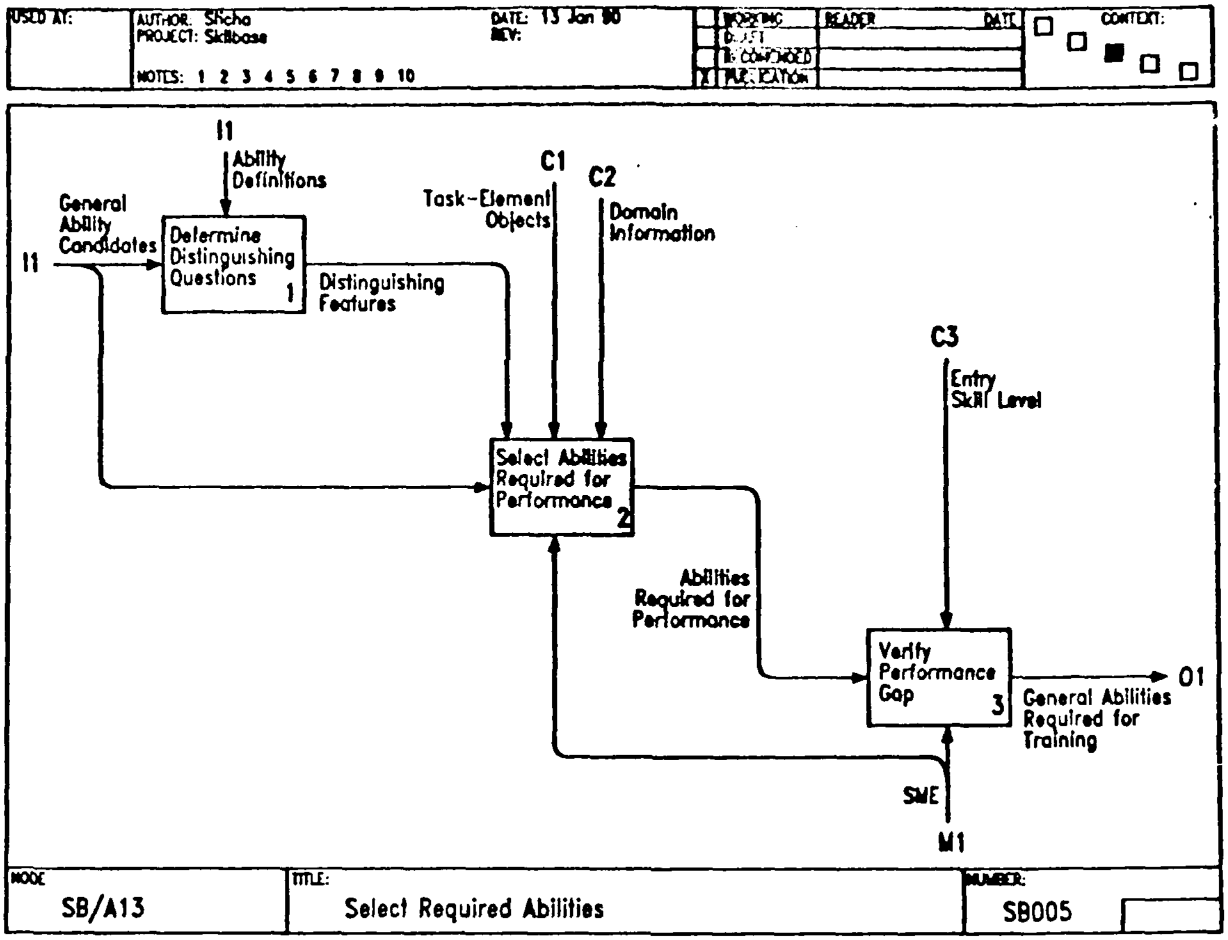


SB/A13: Select Required Abilities

This activity selects the general abilities that are required for training, based on the candidate abilities that were generated by the previous activity (A12). The activity uses information contained in task-element descriptions, information about the job domain, and other information provided by the SME to select those skills that are actually required for job performance. The abilities required for performance for which students have a low entry skill level are required for training.

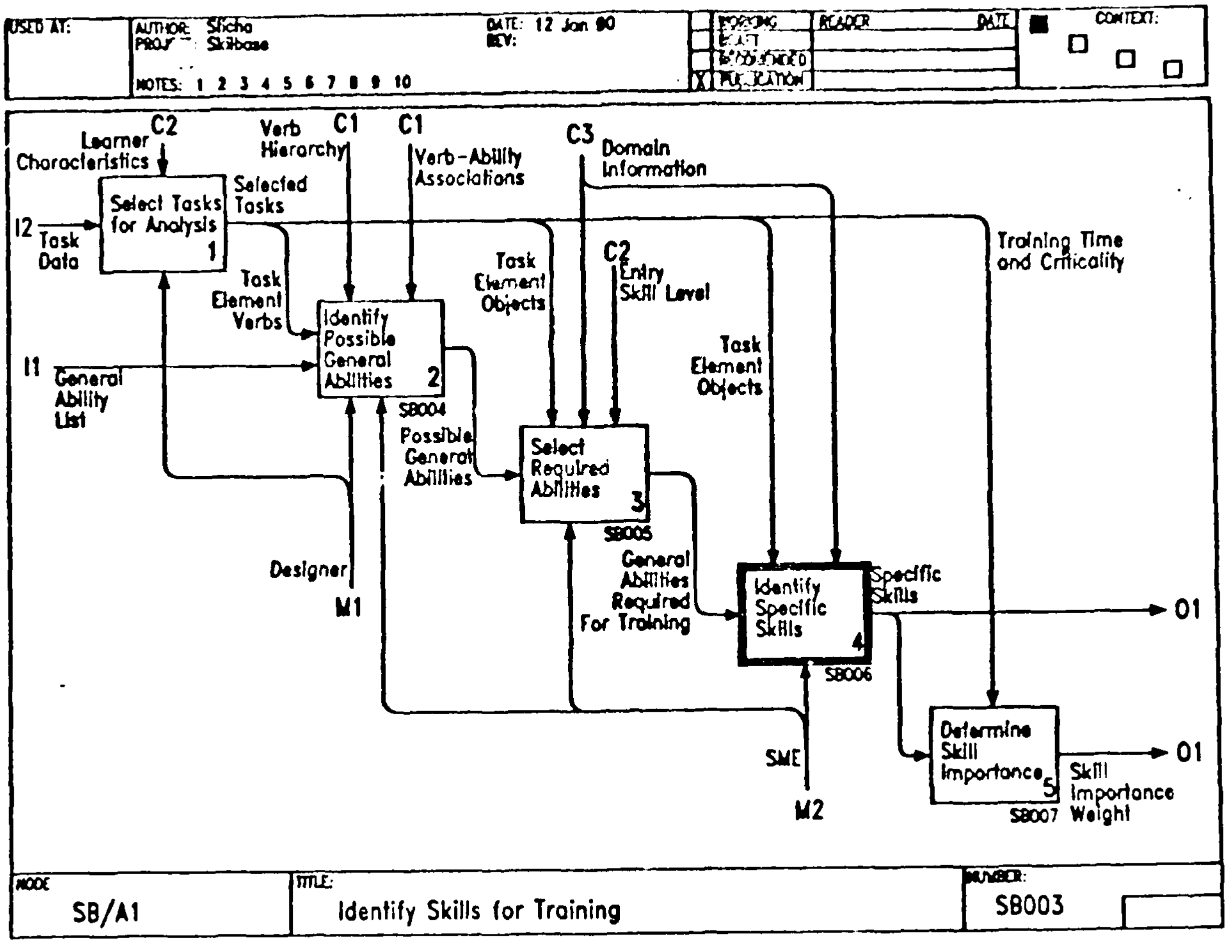
SB/A131: Determine distinguishing questions. This activity determines the characteristics that can be used to distinguish the alternative general abilities that may be involved in a task element. The characteristics are based on the general ability definitions. Each general ability is defined by a set of rules with conditions that specify the kinds of activities, objects, and domain characteristics that are associated with each general ability. This activity examines the conditions for all general ability candidates produced by A123 and identifies those conditions that distinguish the candidate abilities.

SB/A132: Select abilities required for performance. This activity examines available information about the task-element objects, and domain characteristics as controlled by the conditions identified in A131 to select the general abilities



that are required for performance from the candidates identified in A123. Where the existing task-analytic information is not sufficient to distinguish alternative skills, the SME will be asked to provide additional information. The output of this activity is a set of abilities that are required for job performance.

SB/A133: Verify performance gap. In this activity, the SME will be asked to provide the entry skill level for each general ability. The task entry performance level will be used as an anchor to obtain the skill level, which will be measured on the same scale as entry task performance. Those abilities for which the student is already competent are eliminated from further analysis. The remaining abilities are those for which training is required.

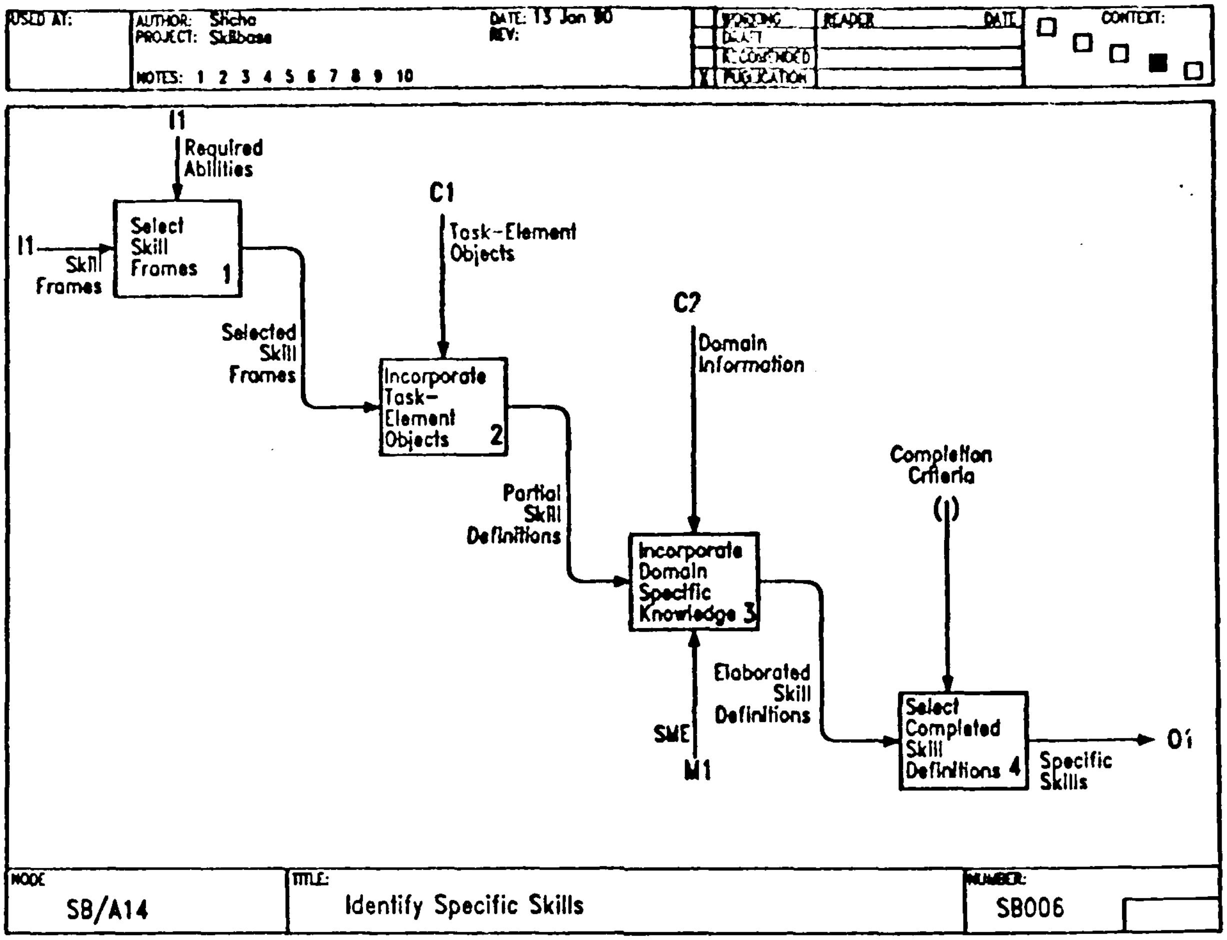


SB/A14: Identify Specific Skills

This activity converts the general abilities required for training into more detailed descriptions of specific skill requirements. Each general ability is associated with a frame or template that specifies the kind of information that is required to develop a complete definition of a specific instance of that general ability. Information to complete the definition comes from the task analysis, job domain information, and SME knowledge. It is possible that general skills that were incorrectly identified in the previous activity (A13) were not eliminated by the checks performed in that activity. In that case, they would be eliminated in this activity, because it would not be possible to develop a complete skill definition. This activity is performed in the following steps.

SB/A141: Select skill frames. This step retrieves from the general ability data base a skill frame or template for each general ability required for learning. The skill frame lists the kinds of information that are required to produce a complete definition of a specific skill.

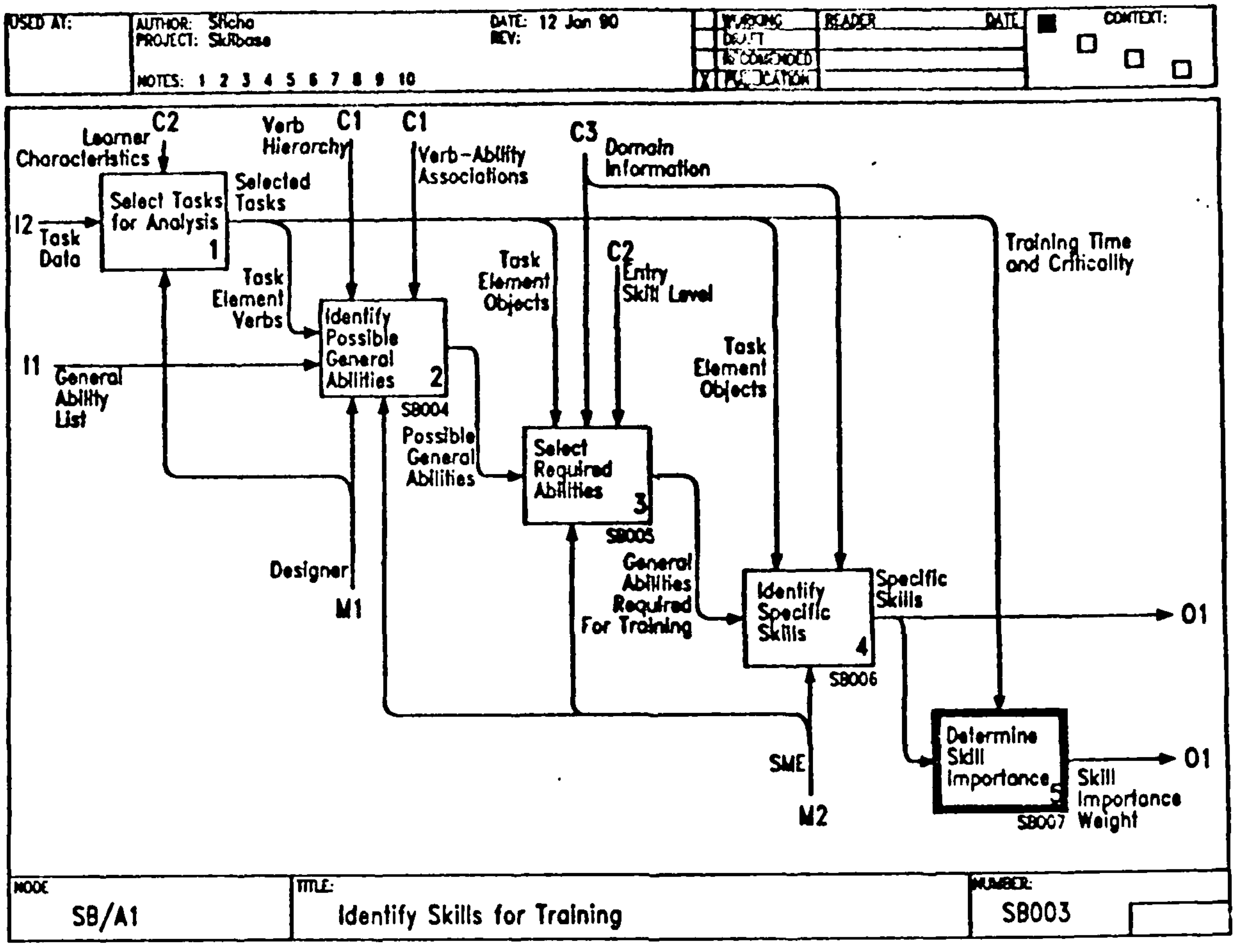
SB/A142: Incorporate task-element objects. Much of the information required by the skill frames is contained in the task-element descriptions associated with each instance of a general ability. Specifically, the task-element



objects will be critical components of a complete specific skill description. This step transfers the task-element objects to the appropriate slots of each skill frame.

SB/A143: Incorporate domain-specific knowledge. Domain information, such as the characteristics of displays and controls, and operating conditions, will also provide a major source of information to complete the specific skill definitions. Some of this information is a part of a task analysis, other information will need to be assessed directly from the SME. The output of this step will be specific skill definitions that are elaborated to the extent possible given available information.

SB/A144: Select completed skill definitions. This step checks the specific skill definitions for completeness, and eliminates any incomplete definitions. Incomplete skill definitions are an indication that the general ability is not really required, but was not eliminated in A13. Consequently, these incomplete frames are not considered further in the analysis.



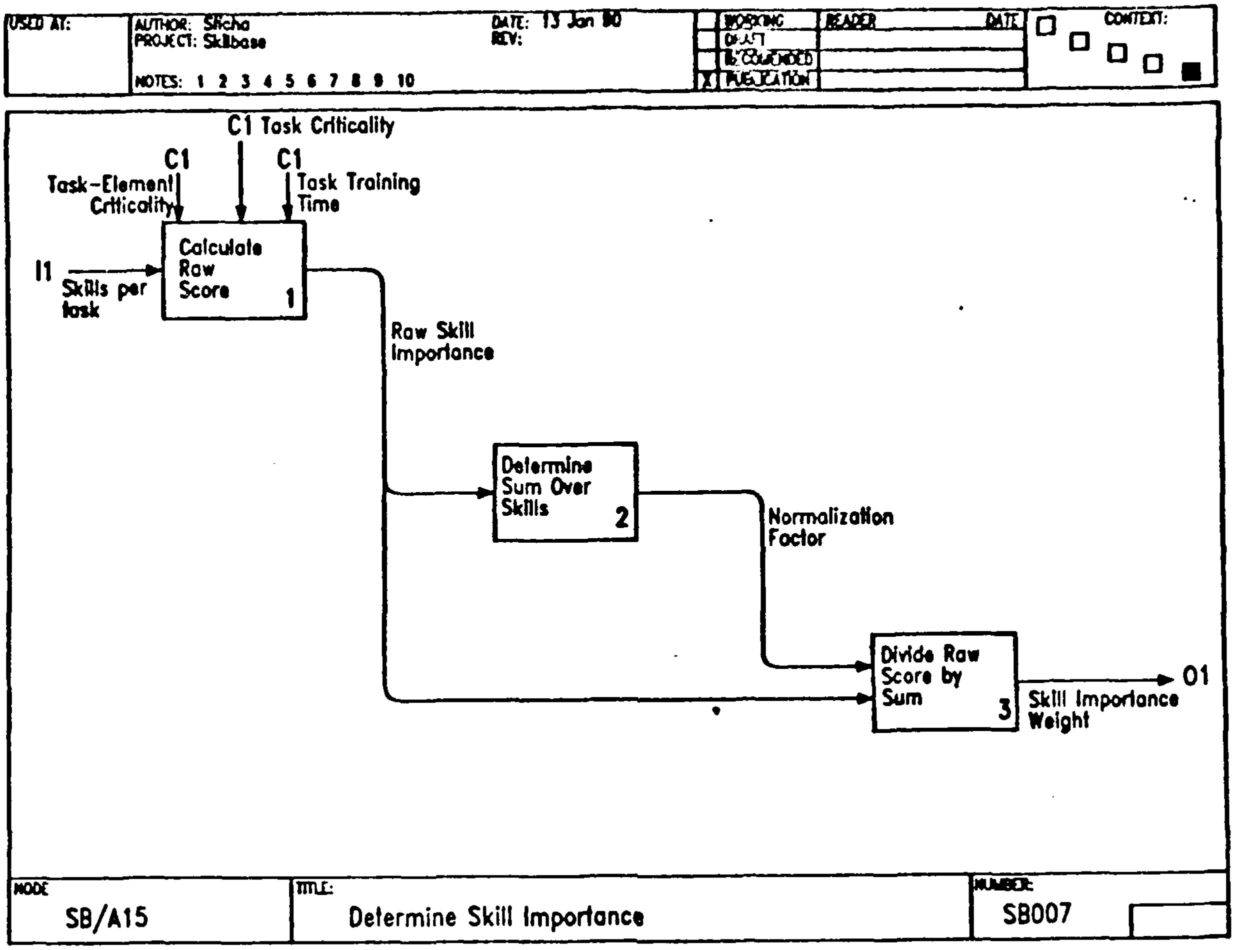
SB/A15: Determine Skill Importance

This activity combines task and task-element information to produce a weight that represents the relative importance of each skill.

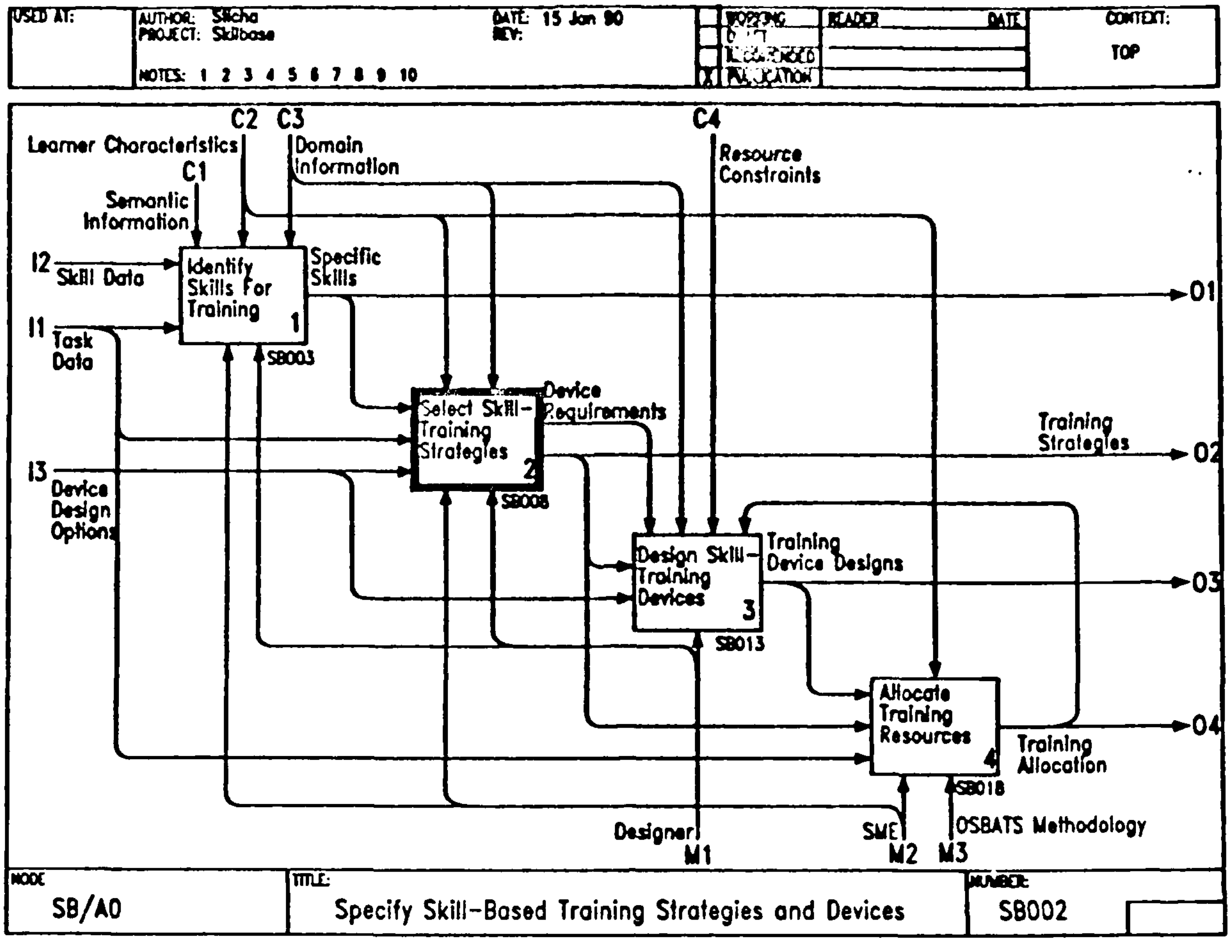
SB/A151: Calculate raw score. This step calculates a raw skill importance measure for each specific skill from the input values. The raw skill importance weight apportions the task importance over the skills that compose the task. The task importance is measured by the time required to train the task to standard (or total task training time using actual equipment). The skill importance weight is the product of (a) the task importance and (b) the ratio of task-element criticality to task criticality for the task element from which the skill was generated, divided by (c) the number of skills that compose the task.

SB/A152: Determine sum over skills. This step determines the total weight for all skills. The total weight is the sum of the raw skill importance measure over all specific skills. This sum used in the following step to develop an importance weight that sums to 1.0 over all specific skills.

SB/A153: Divide raw score by sum. This step divides the importance weight for each specific skill by the sum calculated in A152. The resulting



importance weight may be then viewed as a percentage, since the total weight, summed over all specific skills, is 1.0.

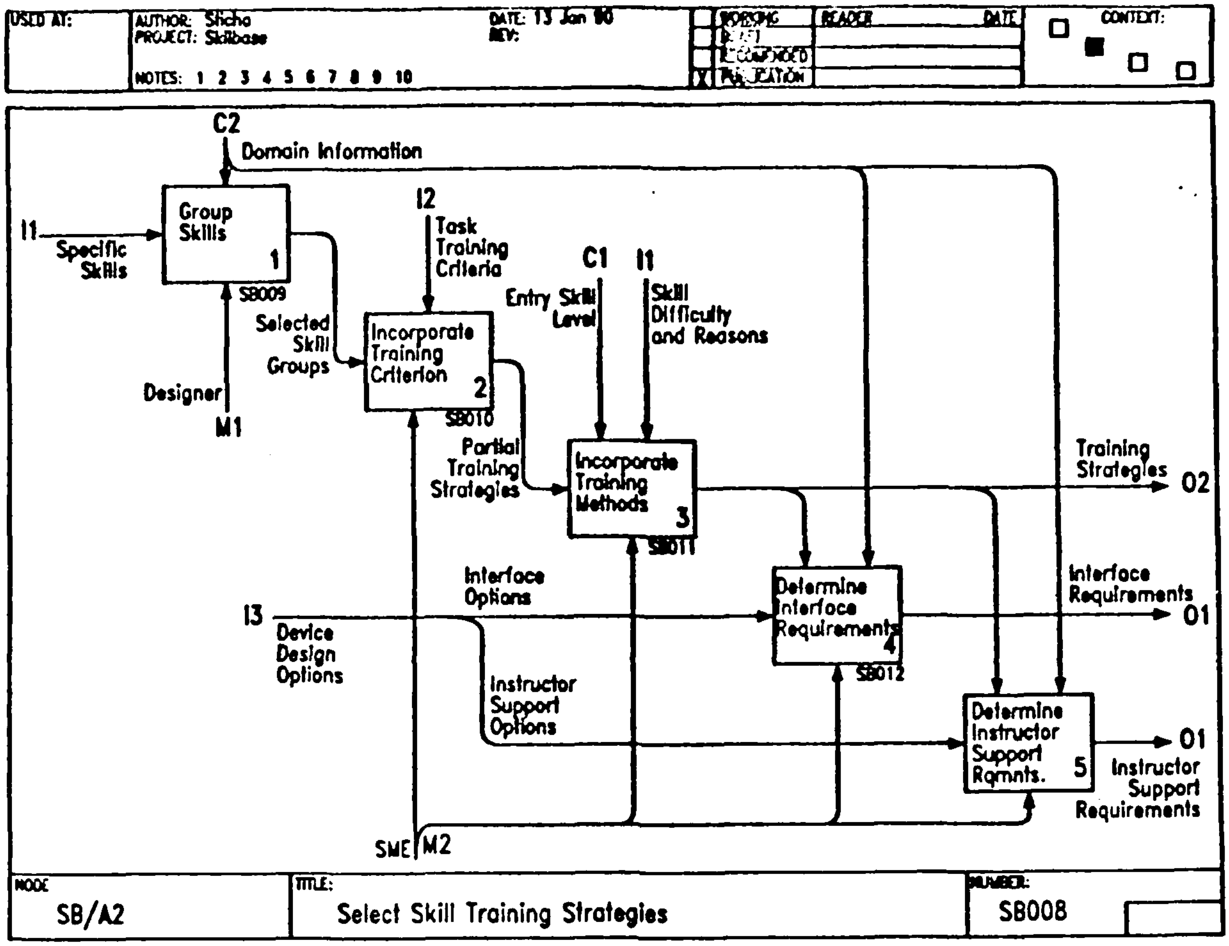


SB/A2: Select Skill Training Strategies

This activity selects skill training strategies for each skill identified in A1. The skill training strategies specify the skills that should be trained together, the training criteria for skill groups, and the training sequence for skill training. For each training strategy, the activity calculates the interface requirements and the instructor support requirements.

SB/A21: Group skills. This step combines skills into groups that would be trained together using the same training device. The skills are grouped according to the objects of the skills and the general ability involved. Thus, skills in a group all involve the same display or control panel, and will involve a single general ability, such as pattern recognition, or visualization.

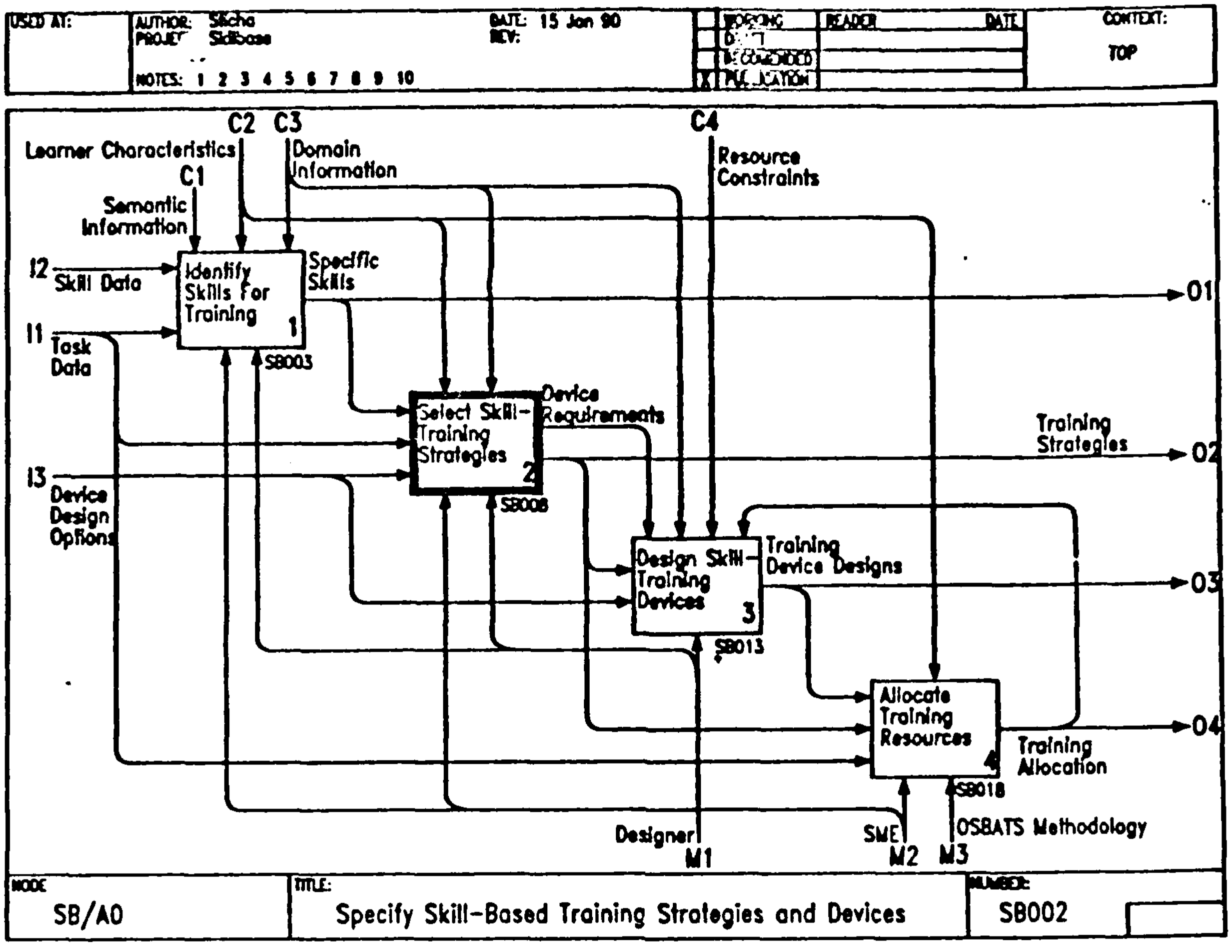
SB/A22: Incorporate training criterion. This step assigns a skill training criterion to each skill group identified in the previous step (A21). The skill training criterion reflects the training criteria for the tasks that are supported by the skills in a group, but the characteristics of the skills may indicate that the skills should be trained to a higher or lower standard than the task performance criterion.



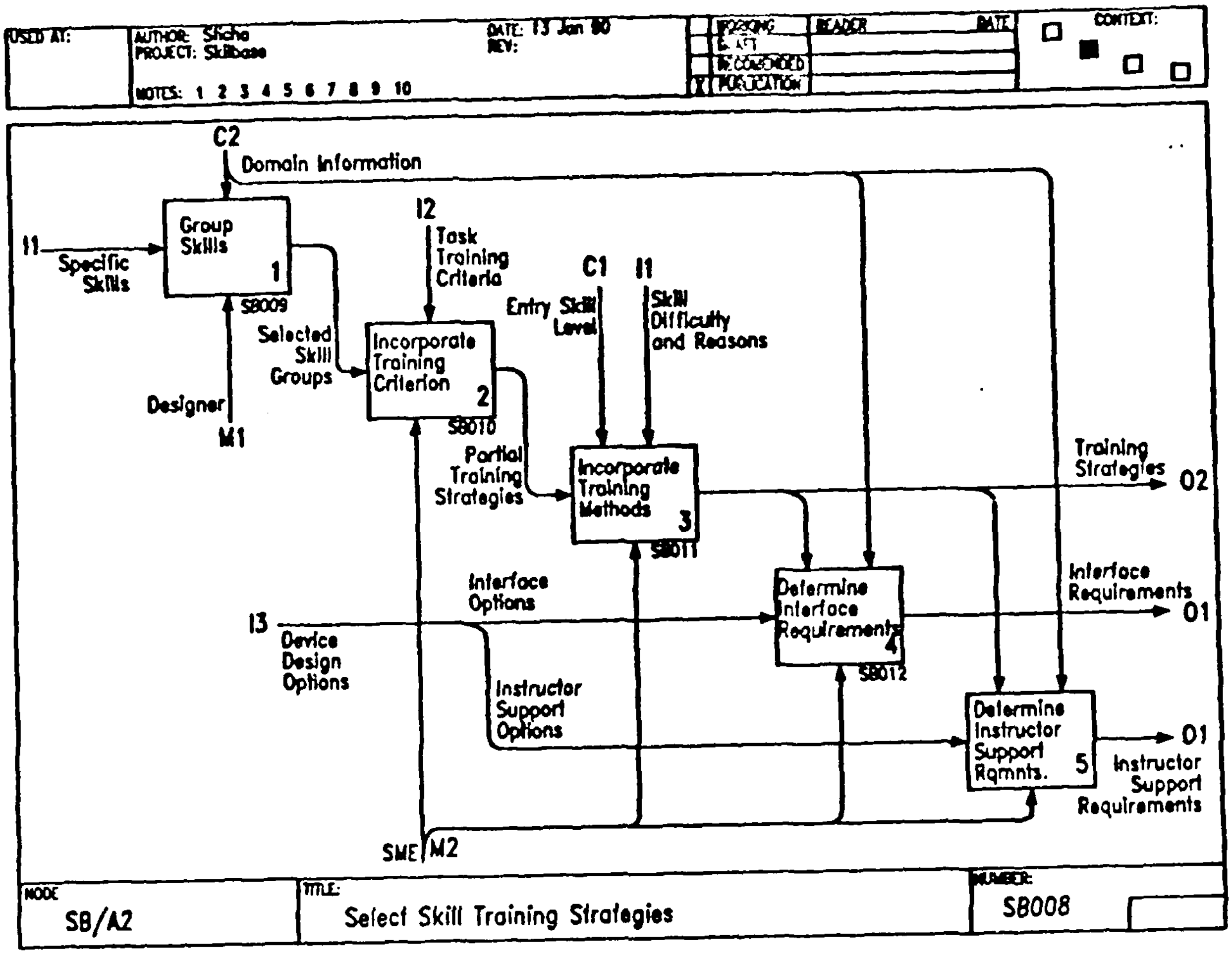
<u>SB/A23: Incorporate training methods</u>. This step determines whether the skill group requires or would benefit from certain training methods that have implications on training-device design. These methods include part-task training methods (segmentation, simplification, and fractionation), procedural or cognitive pretraining, or use of augmented cues or feedback. This step does not perform a comprehensive analysis of training method; rather, it concentrates on specific methods that have known implications on training-device design. The analysis is based on research that investigated the conditions under which Part-Task Training strategies should be recommended (Knerr, et al., 1986).

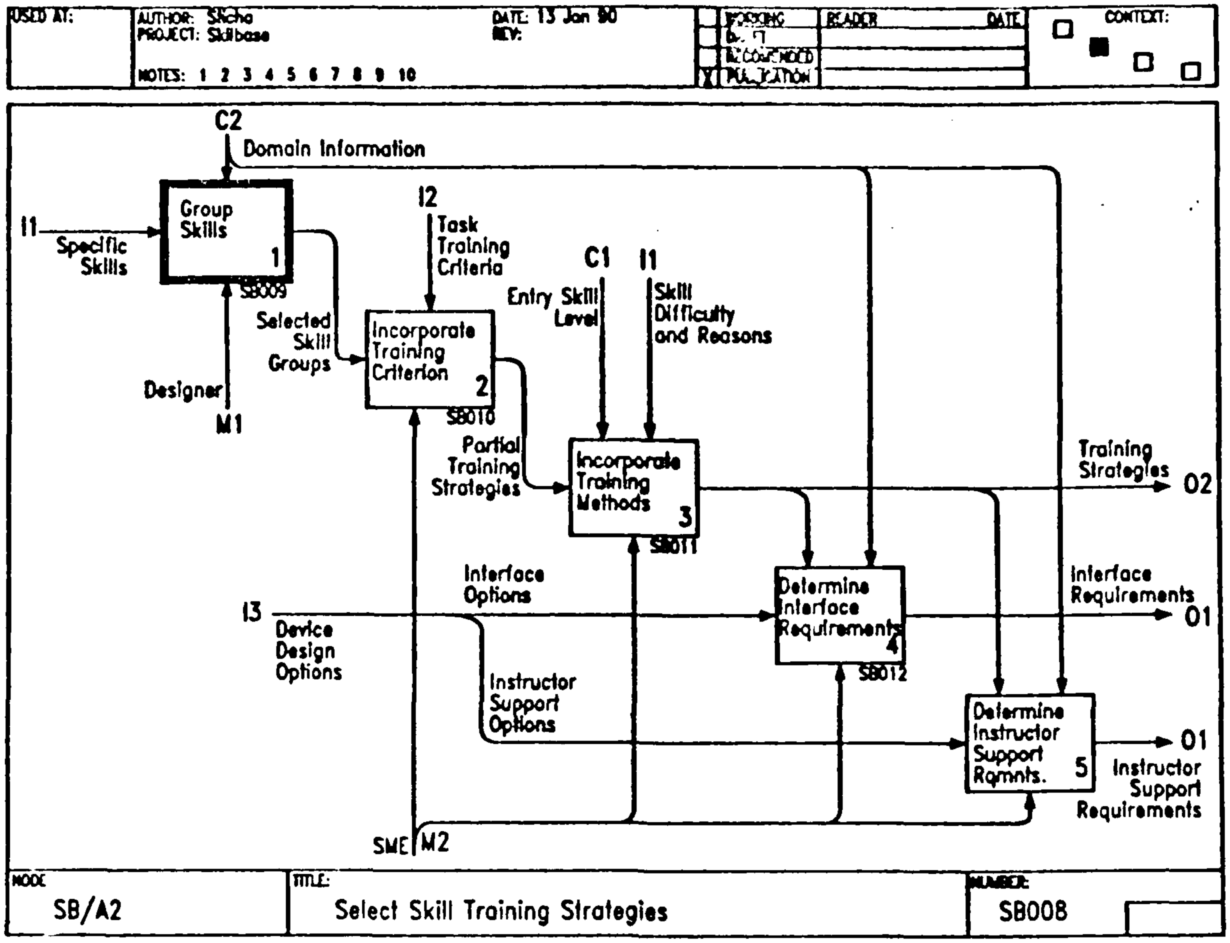
<u>SB/A24: Determine interface requirements</u>. This step determines interface requirements for each skill group. Interface requirements refer to the ability to provide appropriate cues and response feedback for skill acquisition. Specific interface dimensions specify the characteristics of visual displays, controls, simulation capabilities, special effects, and so forth. This activity determines which interface dimensions are relevant for a skill group, and what levels of performance are required to train the skill group to the skill training criterion. The output this process is a listing of the relevant interface dimensions and the performance level on each dimension required for training.

<u>SB/A25: Determine instructor support requirements</u>. This activity determines the instructional support features that are appropriate for each skill



group. The selected instructional support features depend upon the skill entry level performance, the skill training criterion, the skill sequencing option that is selected, the general ability involved, and domain information. The process may be viewed as an expert system that obtains information from the task analysis results and skill training strategy definitions, and supplements this information with domain information obtained directly from the SME when it is required. The rules will specify which instructional features can improve training efficiency as a function of skill characteristics. Most information required by this activity will be available from task analysis or from previous processes. However, additional information provided by the SME will probably also be required. The output of this activity is an instructional feature-by-skill group matrix that indicates which instructional features will enhance the training efficiency for each skill group. The value 1.0 in a cell of the matrix indicates that the instructional feature indicated by the row of the matrix can improve the training efficiency of the skill group indicated by the column of the matrix.

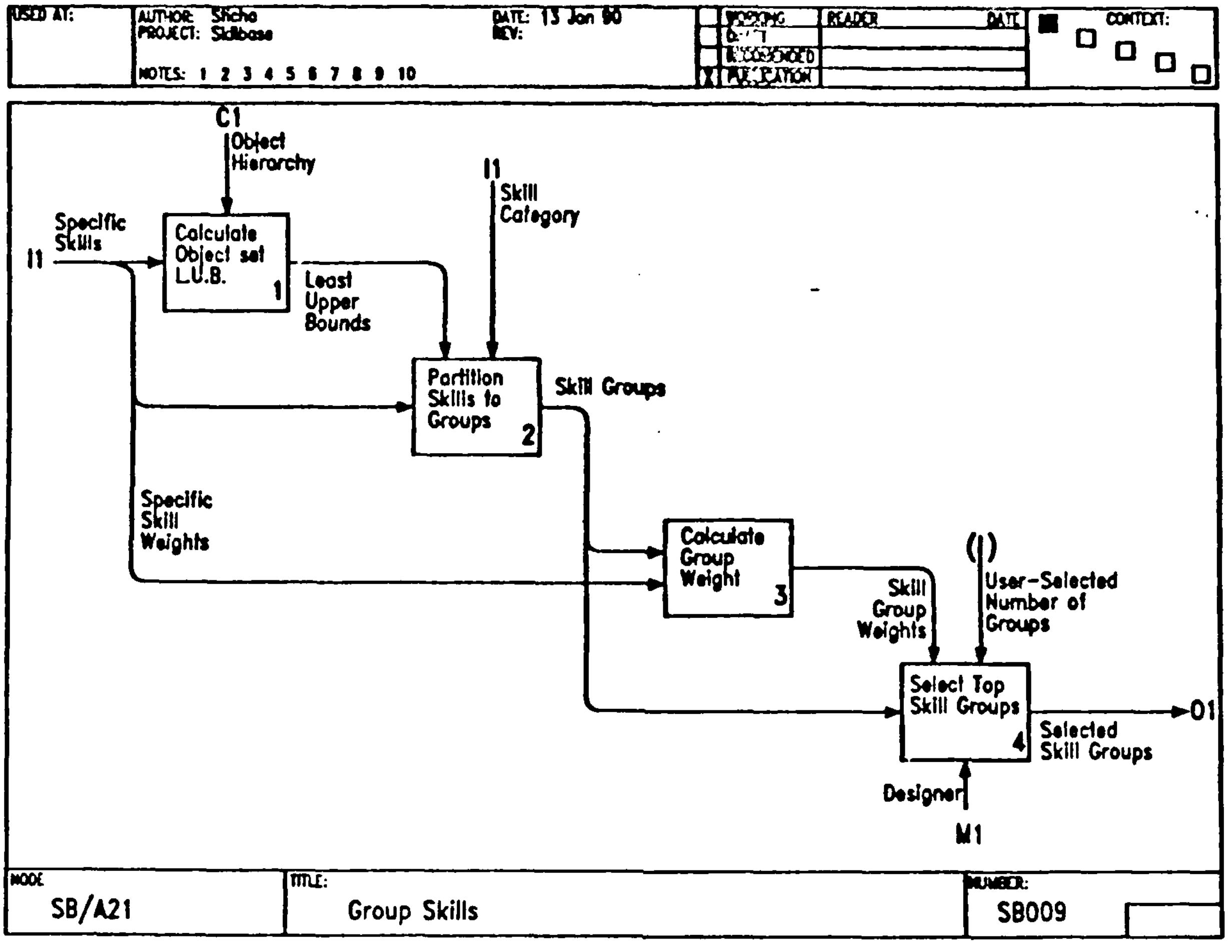

USED AT:
AUTHOR: Shcho
PROJECT: Skillbase
NOTES: 1 2 3 4 5 6 7 8 9 10
DATE: 13 Jan 90
REV:
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C2
Domain Information
I1
Specific Skills
Group Skills
1
SB009
Designer
M1
I2
Task Training Criteria
Selected Skill Groups
Incorporate Training Criterion
2
SB010
C1
I1
Entry Skill Level
Skill Difficulty and Reasons
Partial Training Strategies
Incorporate Training Methods
3
SB011
Training Strategies
O2
Interface Options
I3
Device Design Options
Determine Interface Requirements
4
SB012
Interface Requirements
O1
Instructor Support Options
Determine Instructor Support Rqmnts.
5
O1
Instructor Support Requirements
SME
M2
NODE
SB/A2
TITLE:
Select Skill Training Strategies
NUMBER:
SB008



SB/A21: Group Skills

This activity identifies groups of skills that involve the same displays or controls, and require the same general abilities. The importance weight of the individual skills in a group are combined to yield a group weight, which is used to limit the number of skill groups to the number specified by the training designer.

SB/A211: Calculate object-set least upper bound. The objects included in skill definitions include displays, other sensory cues, controls, visualizations, and other memory representations. We assume that these objects are arranged in a hierarchy. Task analyses often include a hierarchical description of displays and controls. The requirements of this activity are slightly more comprehensive. Each object receives an outline number that indicates it's position in the hierarchy. For example, an object that received the number, 23, is the third minor branch from the second major branch from the top node in the hierarchy. Since the objects are related in a hierarchy, any collection of objects has a unique least upper bound. The least upper bound for two objects is the common beginning of their outline numbers. Thus, if two objects receive the outline numbers 1234 and 1254, their least upper bound is the object 12. For example, a skill that involves searching a single display for several items of information, the objects would be the display and the items of information. The least upper bound would be the display, since

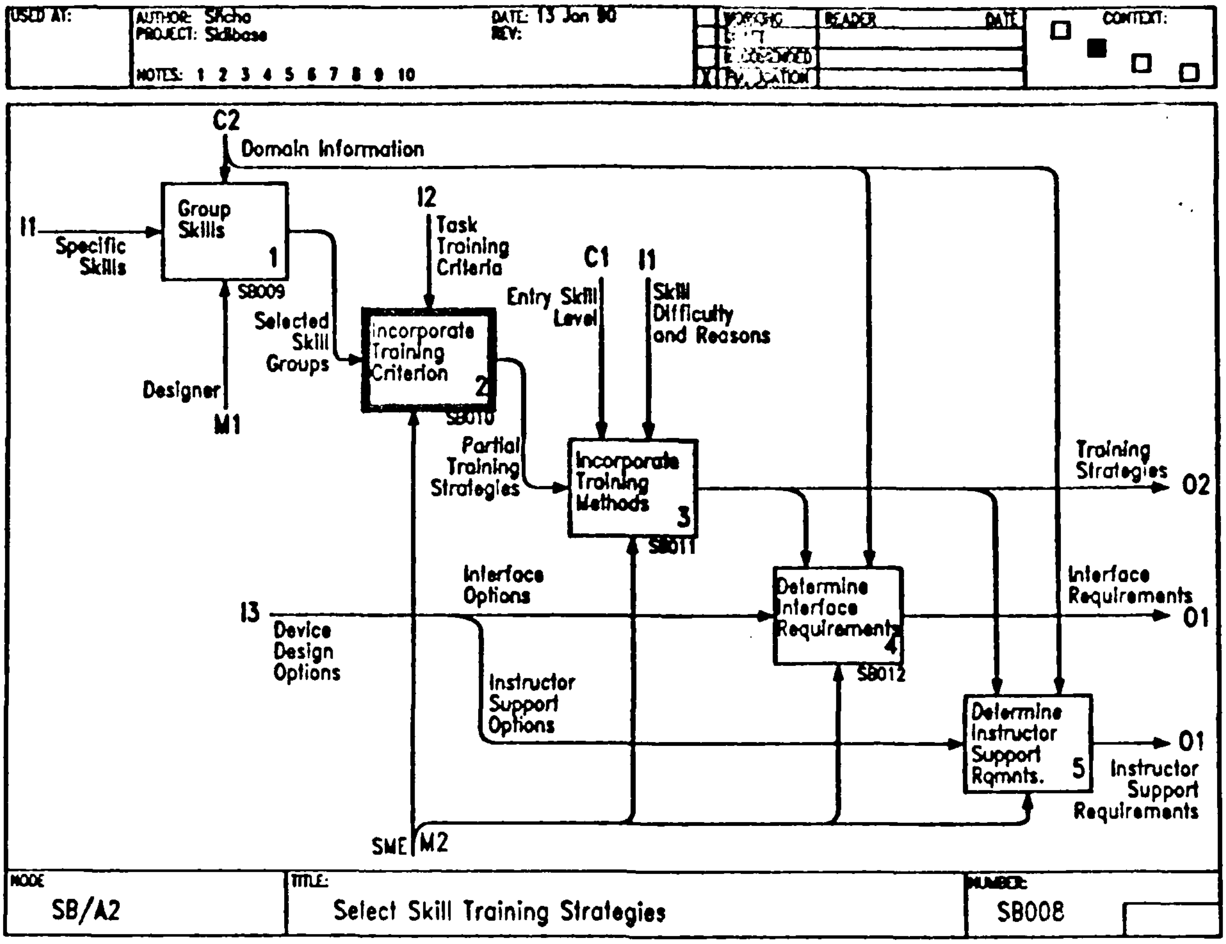


the information is a direct descendent of the display in the hierarchy. This step determines the least upper bound of the set of objects for each specific skill.

SB/A212: Partition skills to groups. This step partitions the set of skills into groups that have the same object least upper bound and involve the same general ability. For example, all skills that involve recognizing patterns from a single display are placed in the same group. Since the skills are partitioned, each skill is placed into one and only one group. A group may consist of one or more skills.

SB/A213: Calculate group weight. This step determines the importance weight for a group of skills by adding the weights for each skill within the group. Since the skill groups partition the set of specific skills, and since the specific-skill weights sum to 1.0, the group weights will also sum to 1.0.

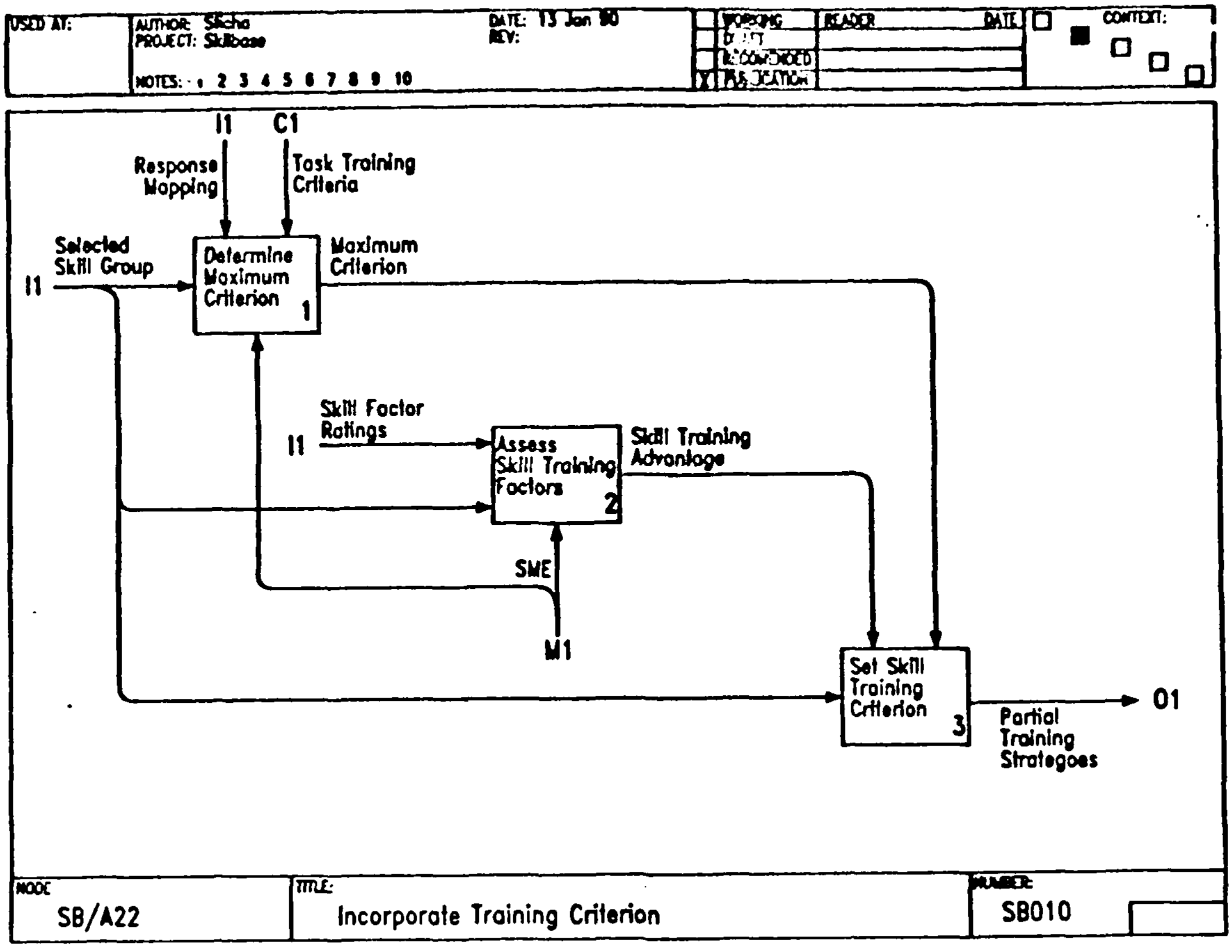
SB/A214: Select top skill groups. This step reduces the number of skill groups being considered by the analysis to a number specified by the training designer. First, the skill groups are ranked by group weight. Then, the skill groups with the greatest importance weight are chosen for further analysis.



SB/A22: Incorporate Training Criterion

This activity specifies a training criterion for each skill group, and incorporates the criterion into the definition of the skill training strategy. The first step determines the maximum training criterion for the skill group, depending on the training criteria of the tasks supported by the skills in the group and the characteristics of the skills. The second step determines the extent to which skill characteristics would favor skill training as opposed to task training. The third step combines the results of the first two processes to recommend a skill training criterion, and includes the criterion in the strategy definition.

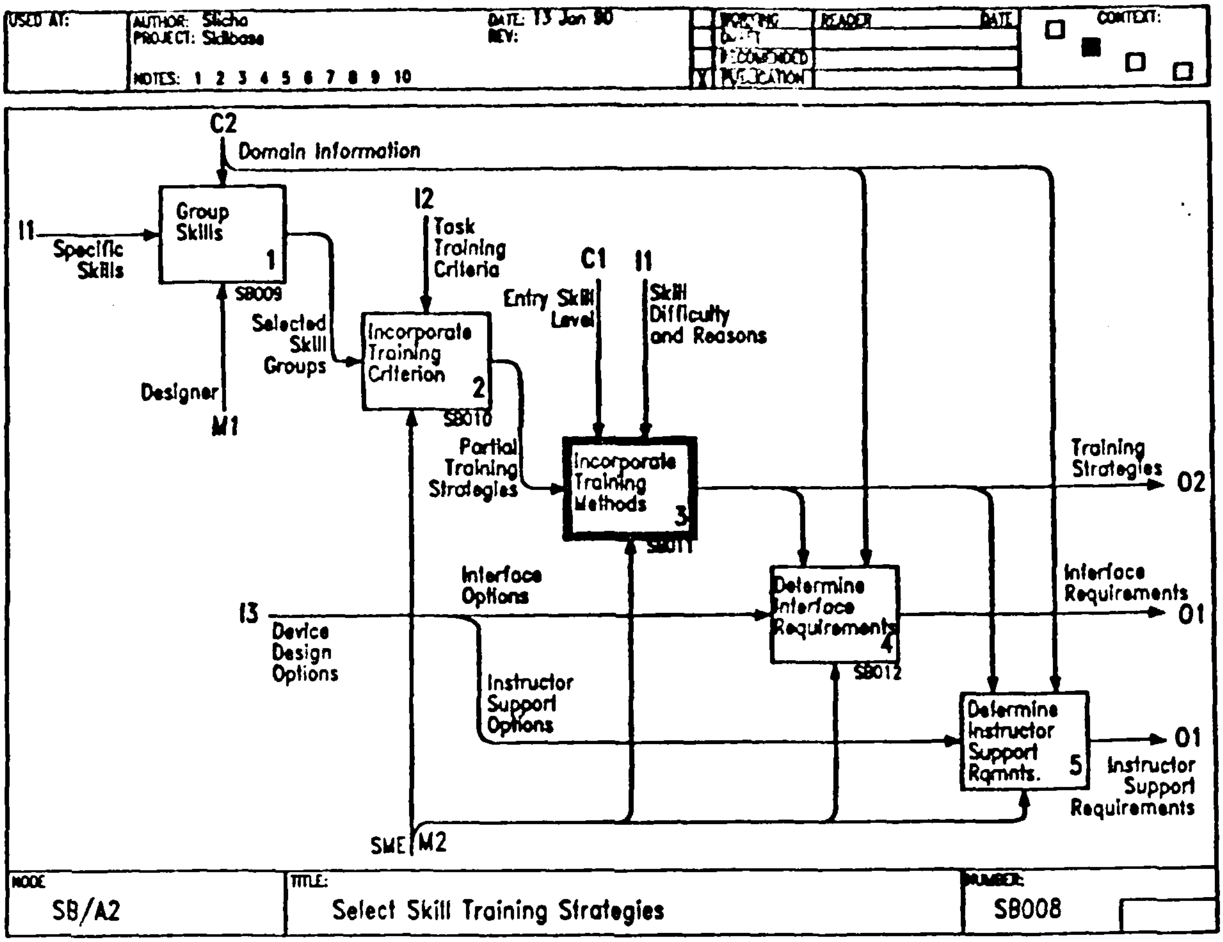
SB/A221: Determine maximum criterion. One way of setting the criteria for skill training is to train each skill to the task training criterion. Thus, if the task requires performance at a mastery level, all skills would be trained to that level. However, for some tasks it may be optimal to train some of the skills to a higher level than the task performance criterion. Training skills to a higher level will be appropriate for skills in which responses are consistently mapped to cues. This activity begins by determining from the SME whether any of the skills in a skill group are consistently mapped. If some of the skills are consistently mapped, then the maximum training criterion is set to a high level representing automaticity. If all are variably mapped, then the maximum skill-group training



criterion is set to the maximum task training criterion for the tasks supported by the skill group.

SB/A222: Assess skill training factors. The skill training criterion depends on factors other than those examined in the previous step (A221). For example, factors such as delay of feedback, insufficient practice in the task context, high workload, and others (as described in the previous section presenting the rationale for skill-based training), provide rationale for conducting skill training to a higher performance level. This activity obtains ratings from the SME of the factors that indicate the relative advantages or disadvantages for skill training, and averages these factors into an index of the values of skill training. The index has a range of values between 0.0 and 1.0, where 0.0 indicates the maximum advantage for task training, 0.5 indicates no advantage for either skill training or task training, and 1.0 indicates the maximum advantage of skill training.

SB/A223: Set skill training criterion. This step calculates the skill training criterion for a skill group to be the product of the maximum criterion calculated in A221 and the index of the advantage of skill training calculated in A222. The skill training criterion is added to the information that is defines the skill training strategy.

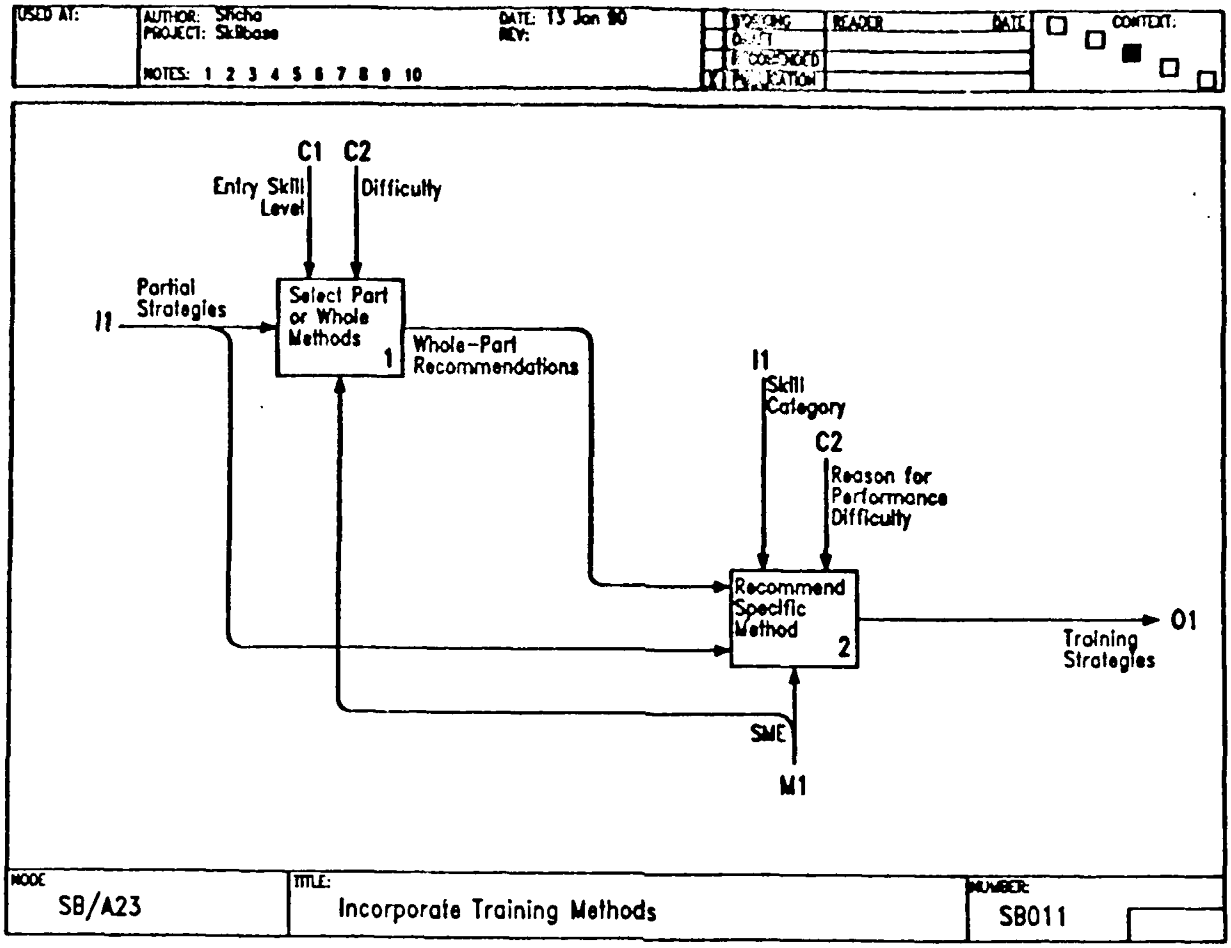


SB/A23: Incorporate Training Methods

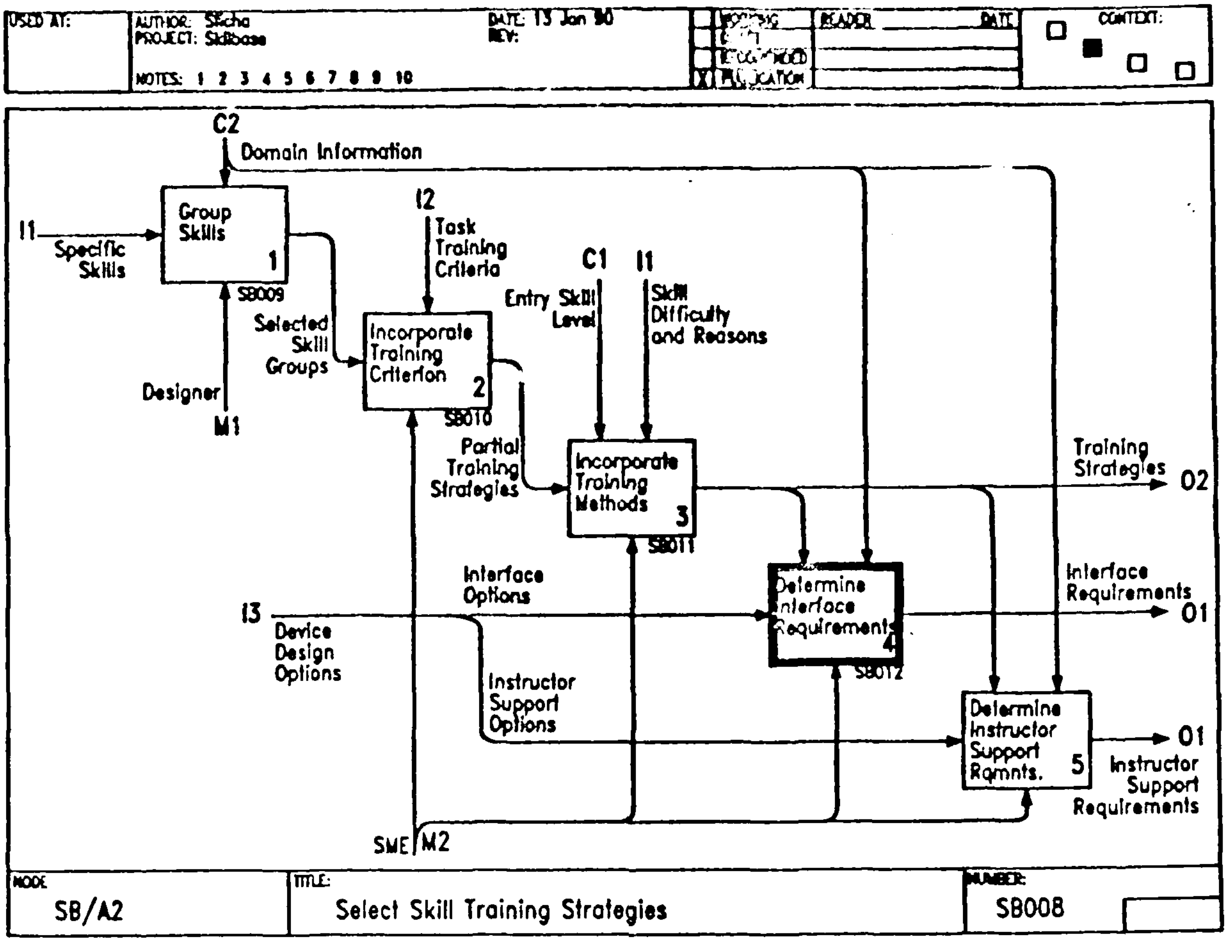
This activity determines whether the skill group requires or would benefit from certain, specified training methods that have known implications on training-device design. These methods include part-task training methods (segmentation, simplification, and fractionation), procedural or cognitive pretraining, or use of augmented cues or feedback. This activity recommends training methods for training individual skills, based on the skill type, the entry skill level, the skill difficulty, and reasons for skill difficulty. The recommendation is added to the information that defines the training strategy.

SB/A231: Select part or whole methods. This step recommends whether skills in the group should be trained using part- or whole-task training methods based on the difficulty of the skills and the entry skill performance. If the skills are very difficult (e.g., they requires more than 100 hours of training) and the entry skill level is low (the student does not know the skill at all), then part-task methods are recommended. Otherwise, whole-skill methods are recommended.

SB/A232: Recommend specific method. This step recommends specific training methods (segmentation, simplification, procedural pretraining, augmented feedback, etc.) for each skill group based on the general ability involved and the reasons that the skills in the group are difficult. The rules that make the



required inferences are derived from the training research literature. For example, this step will recommend a segmentation strategy for procedural skills that are difficult because of their length.

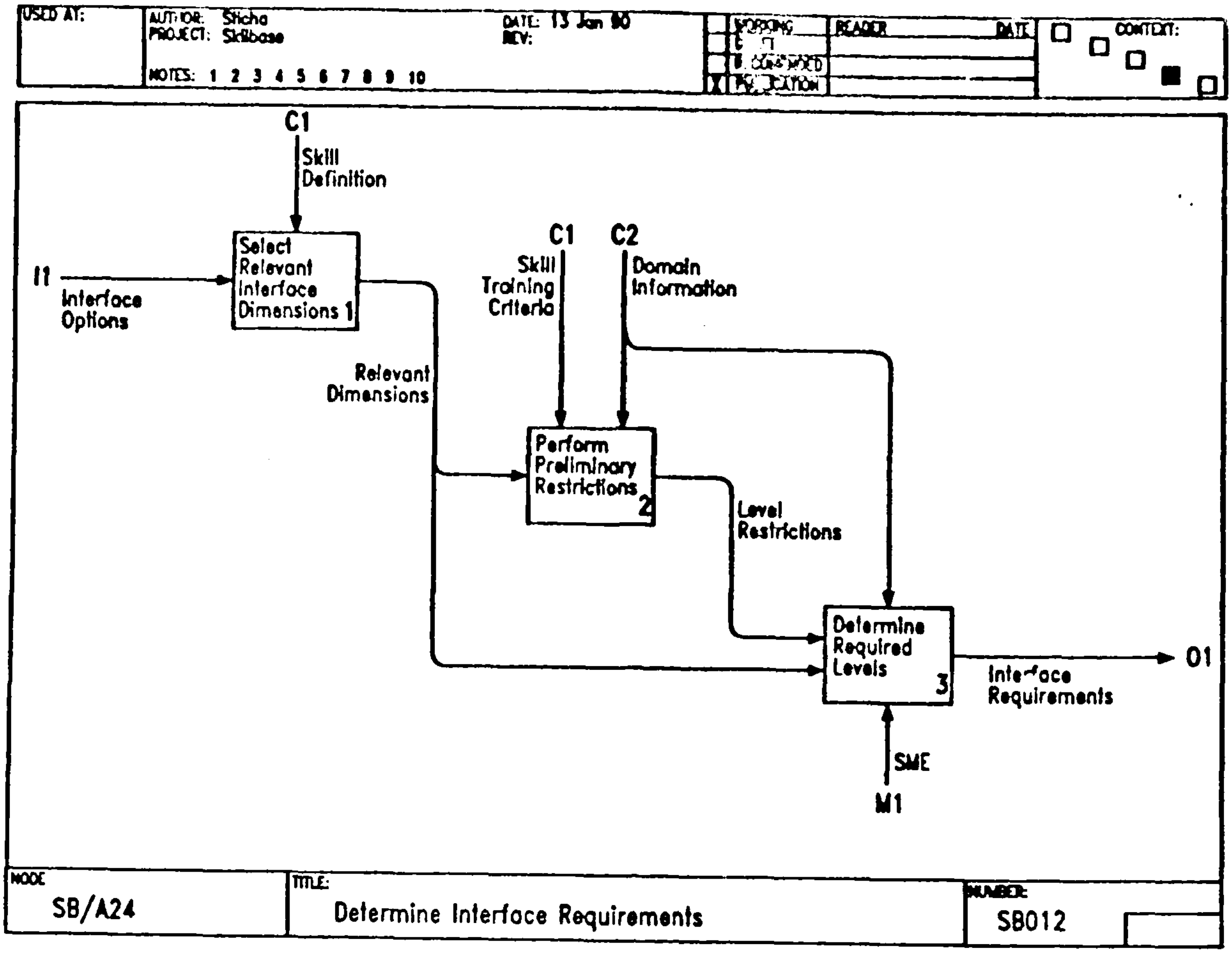


SB/A24: Determine Interface Requirements

This activity determines the requirements to present cues and response feedback for the acquisition of each skill group. To determine interface requirements requires detailed knowledge of the task; much of this detailed information will be provided by the SME. The output of this activity is a set of requirements on several interface dimensions. Both the applicable dimensions and the required levels are determined in the following three steps.

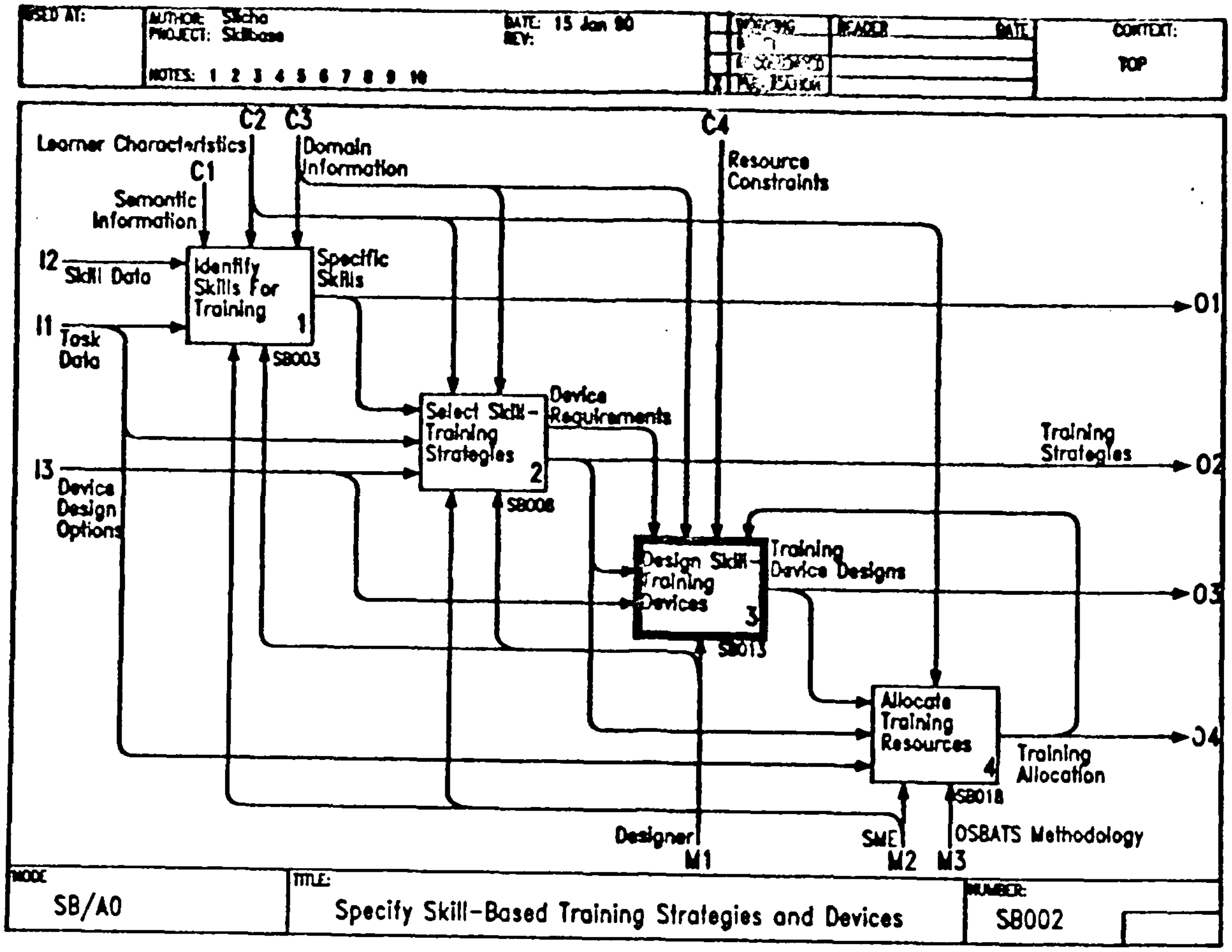
SB/A241: Select relevant interface dimensions. This step selects the relevant interface dimensions based on the skill definition. A set of rules embodies the relationships between skill information and interface dimensions. For example, if the skill requires visual pattern recognition, interface dimensions that describe different auditory cues will be irrelevant, as will dimensions that describe system controls. The output of this task is a set of interface dimensions that will form the basis of the analysis conducted in the next two steps.

SB/A242: Perform preliminary restrictions. This step eliminates some of the levels of interface dimensions that represent either very high levels or very low levels, based on information that is available from the task analyses or previous analyses, including the skill group training criterion that is a part of the skill training strategy and information about the job domain. For example, if the



skill is performed on the job with a very simple display, then more complex options on that dimension may be eliminated. Similarly, if the purpose of skill training is to familiarize the student with displays or controls, only limited capability is required.

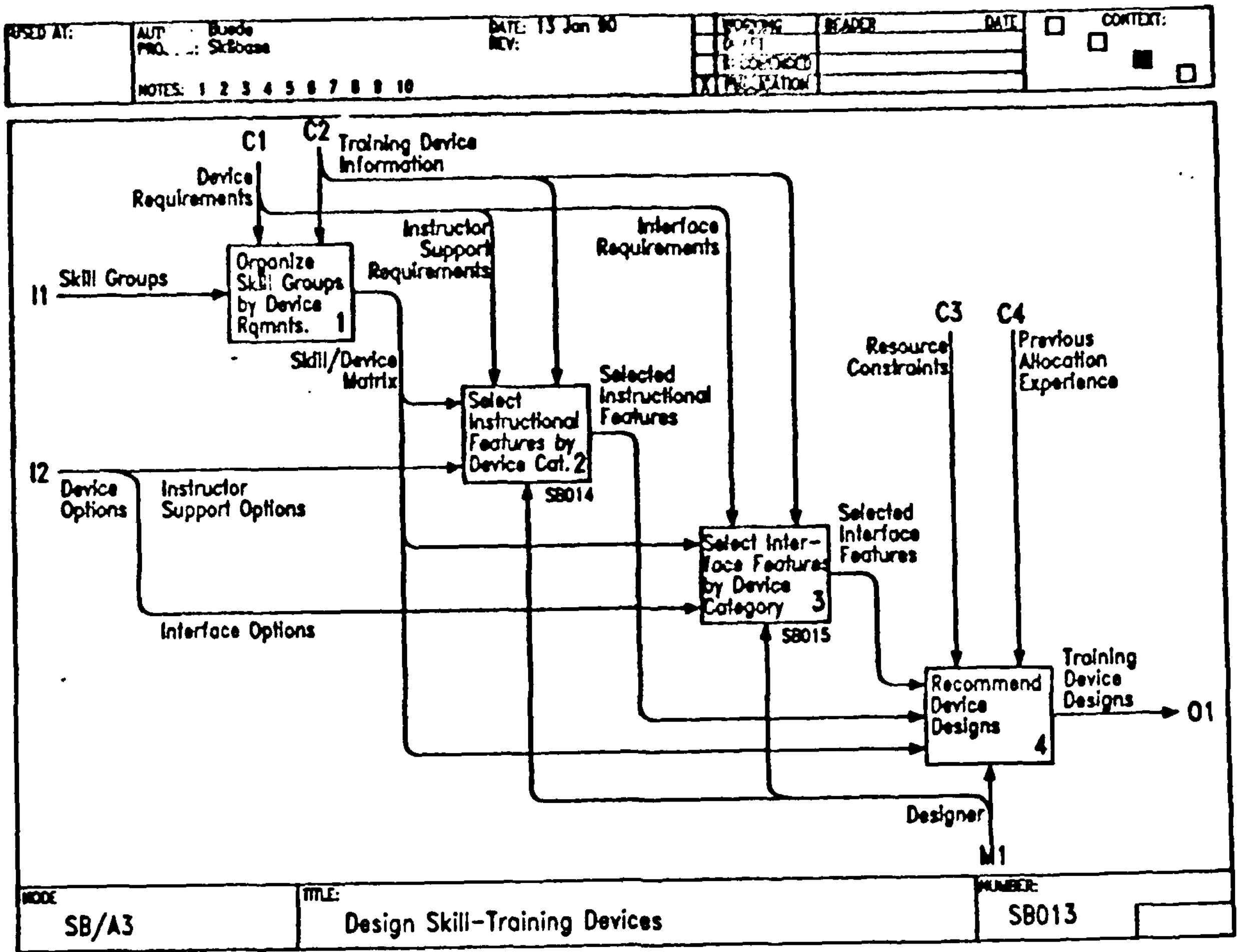
SB/A243: Determine required levels. This step performs an analysis of the interface requirements, based on the detailed skill knowledge of the SME. The analysis system will ask the SME questions about the cues required to perform the skill at a criterion level in the job context. The required levels on the interface dimensions will depend on the SMEs answers to the questions. These questions will address the specific activities, performance cues, and response feedback involved in skilled performance. The analysis performed in this step will specify the required level within the range of options determined in A242.



SB/A3: Design Skill-Training Devices

This activity operates on the skill groups that make up selected skill-training strategies to produce one or more training device designs that meet the device requirements of the particular skills within the resource constraints. The initial step of this activity determines which skills and tasks are associated with each of several general device types. Next, analyses are conducted to select the appropriate instructional features and interface capabilities for each device. A cost-benefit analysis is conducted for each device type to optimize training enhancement per development dollar. These devices are then compared with known resource constraints and experience from allocating training (A4), and devices that are not feasible are dropped from the recommendation.

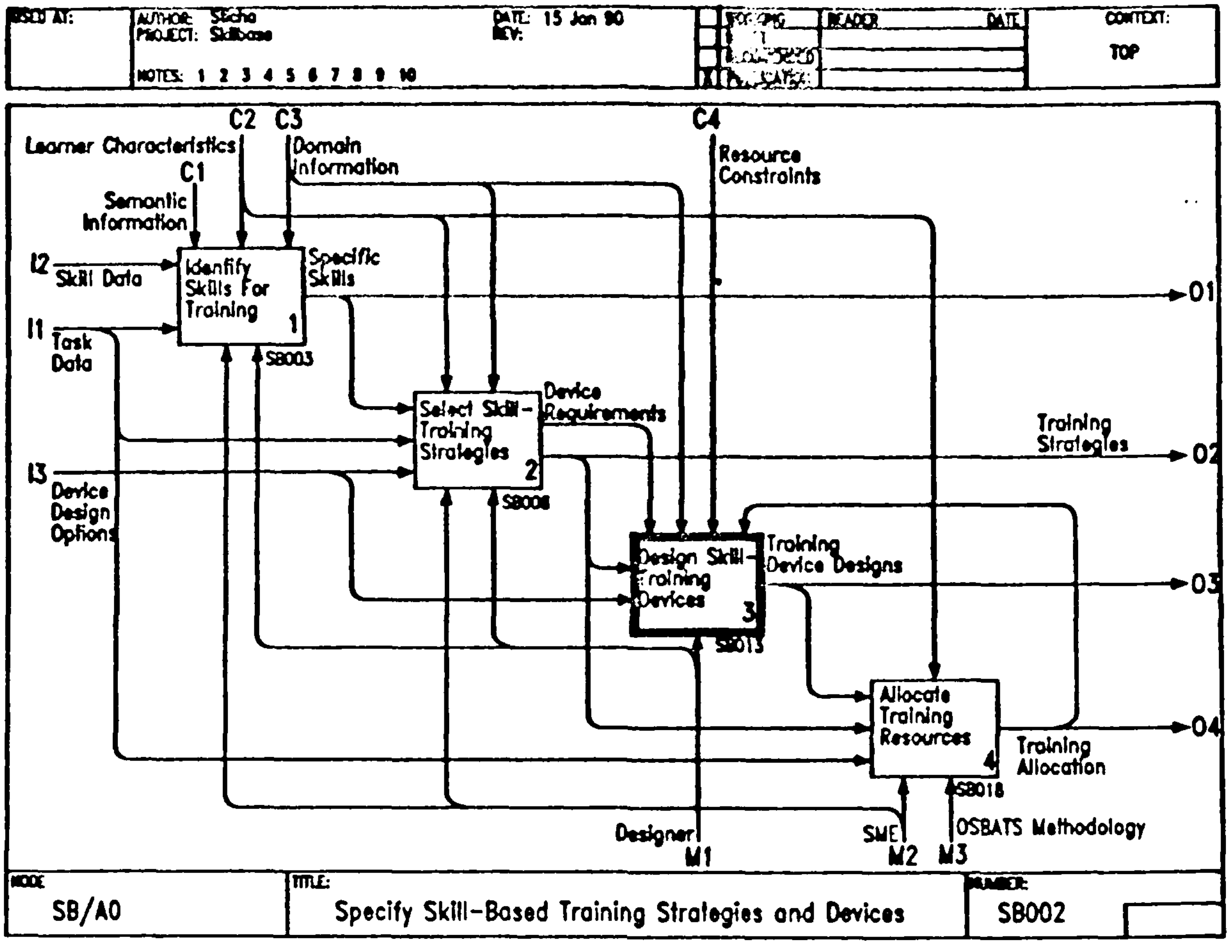
SB/A31: Organize skill groups by device requirements. This process compares the device requirements of the skill groups to the maximum capabilities of classes of general-purpose training device (e.g., microprocessor-based CBI, control procedures trainer, etc.), and assigns the skill groups to a specific class of training device. The general-purpose devices are examined in order of increasing cost so that a skill group will be assigned to the least expensive class of device that has the potential to provide the required training. Skill groups that require features that are not available in any of the general classes of training device are candidates for the development of a specialized training device and may be treated



singly, or as a whole in the following activities. The result is a two-dimensional matrix of device types (including a specialized device) by skill group that reflects the assignment.

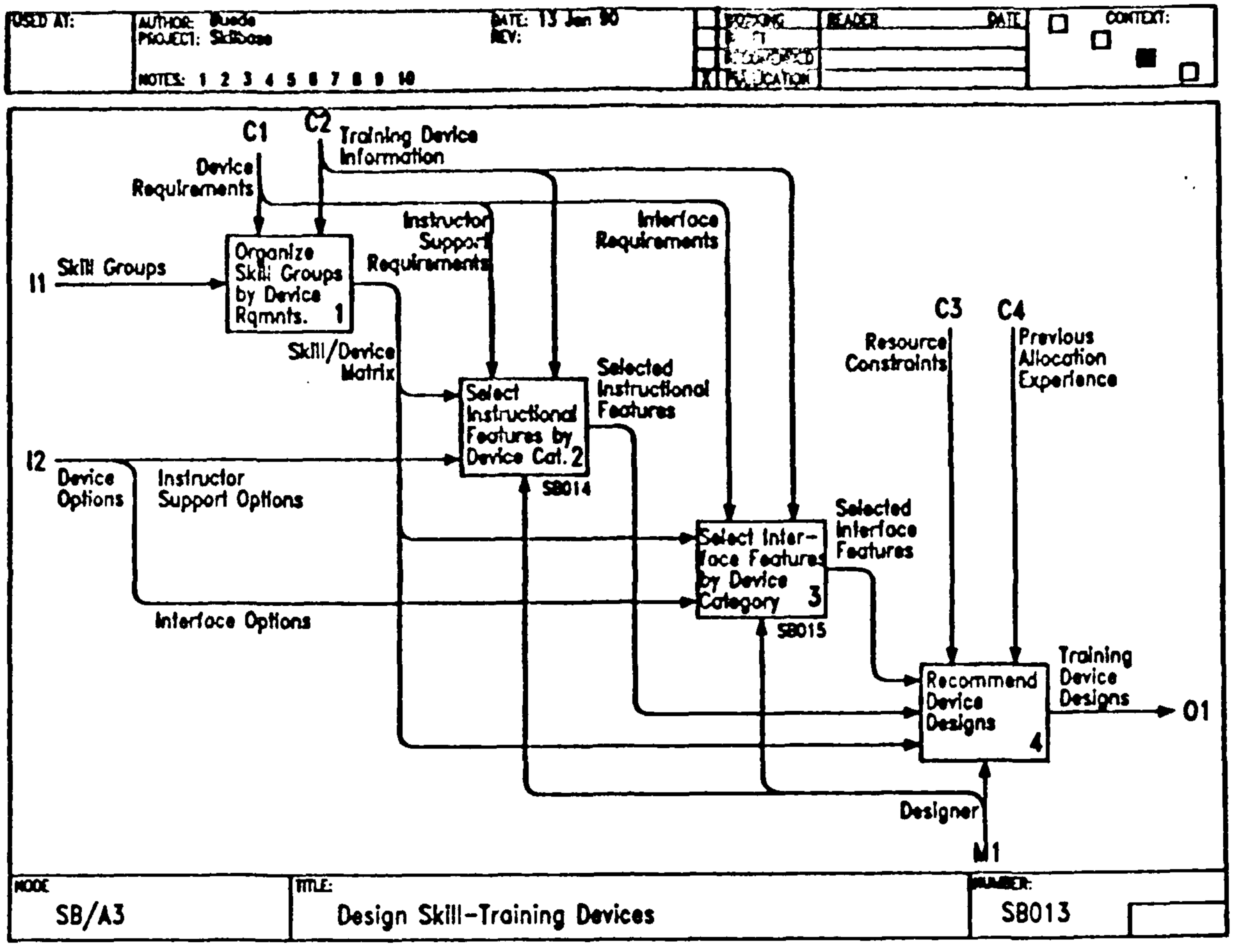
SB/A32: Select instructional features by device. This activity determines the instructional features that are appropriate to train the skills assigned to each training device, based upon the instructor support requirements of the skills to be trained and the capabilities of the class of training device being considered. The subactivities of this activity determine which instructional features have the greatest expected impact on training efficiency, given their cost. The activity produces a list of the instructional features, ordered by decreasing benefit/cost ratio. The designer may eliminate the instructional features from this list that do not provide adequate value, or that exceed resource constraints.

SB/A33: Select interface features by device. This activity determines the computational and interface capabilities that are appropriate to train the skills assigned to each training device, based upon the interface requirements of the skills to be trained and the capabilities of the class of training device being considered. The first subactivity restricts the options considered to be consistent with the interface requirements, maximum device capabilities, and user desires. The second subactivity calculates the cost and benefit of interface options. The third subactivity computes the optimal device designs according to the ratio of

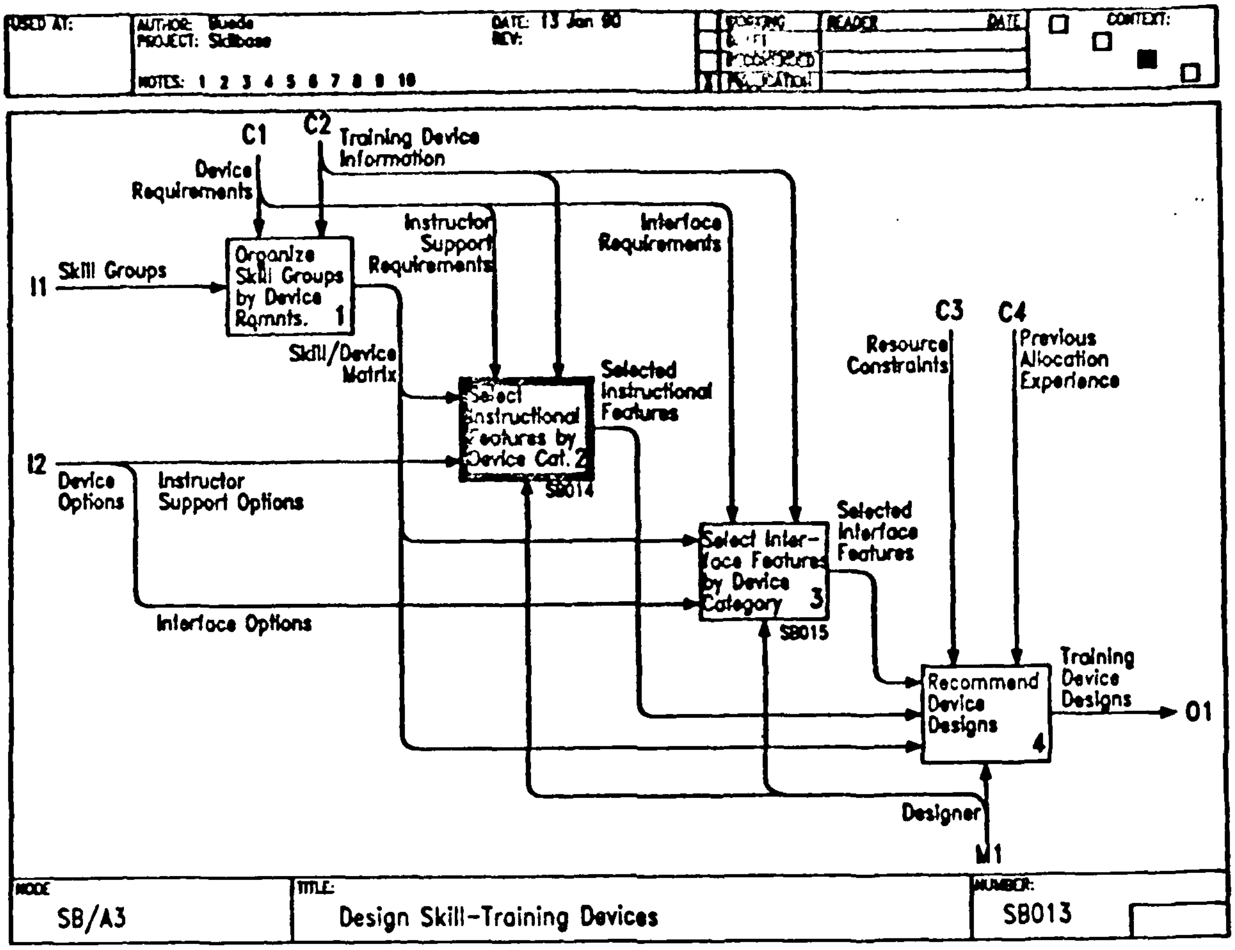


benefit to cost. The activity produces a list of the computational and interface features, ordered by decreasing benefit/cost ratio. The designer may eliminate features from this list that do not provide adequate value, or that exceed resource constraints.

<u>SB/A34: Recommend device designs</u>. This activity performs a cost-benefit analysis to balance the level of computational and interface capabilities with the level of instructional features. In determining the overall benefit, the benefit for instructor support features is divided by its maximum value to put it in the range, [0,1]. Then the overall benefit due to interface features may be weighted equally to the overall benefit due to instructor support features, because both benefits are measured on a scale in which 1.0 signifies that the option meets all skill group requirements. However, the designer has the freedom to modify these weights based upon experiences from allocating training (A4). The cost in this analysis is the development cost of the devices. The relative benefit of the interface capabilities and instructor support features are part of the designs determined in A32 and A33. The designer may obtain a recommended design by specifying one of the following three types of constraints: (a) The designer may specify the target cost. The system will then identify the device design (i.e., the combination of interface and instructor support features) that provides the greatest benefit at that cost or less. (b) The designer may specify the target benefit. The system will identify the device design that provides at least the target benefit at the lowest



cost. (c) The designer may specify a minimum configuration, that is, a set of features that must be included in the design. The system will then identify a system design that includes all required features and those features that are more efficient (based on benefit/cost ratio). The selection is made by selecting interface or instructor support features in order of benefit/cost ratio until one of the constraints is met. The recommended device design is forwarded to A4 for consideration in allocating training resources.

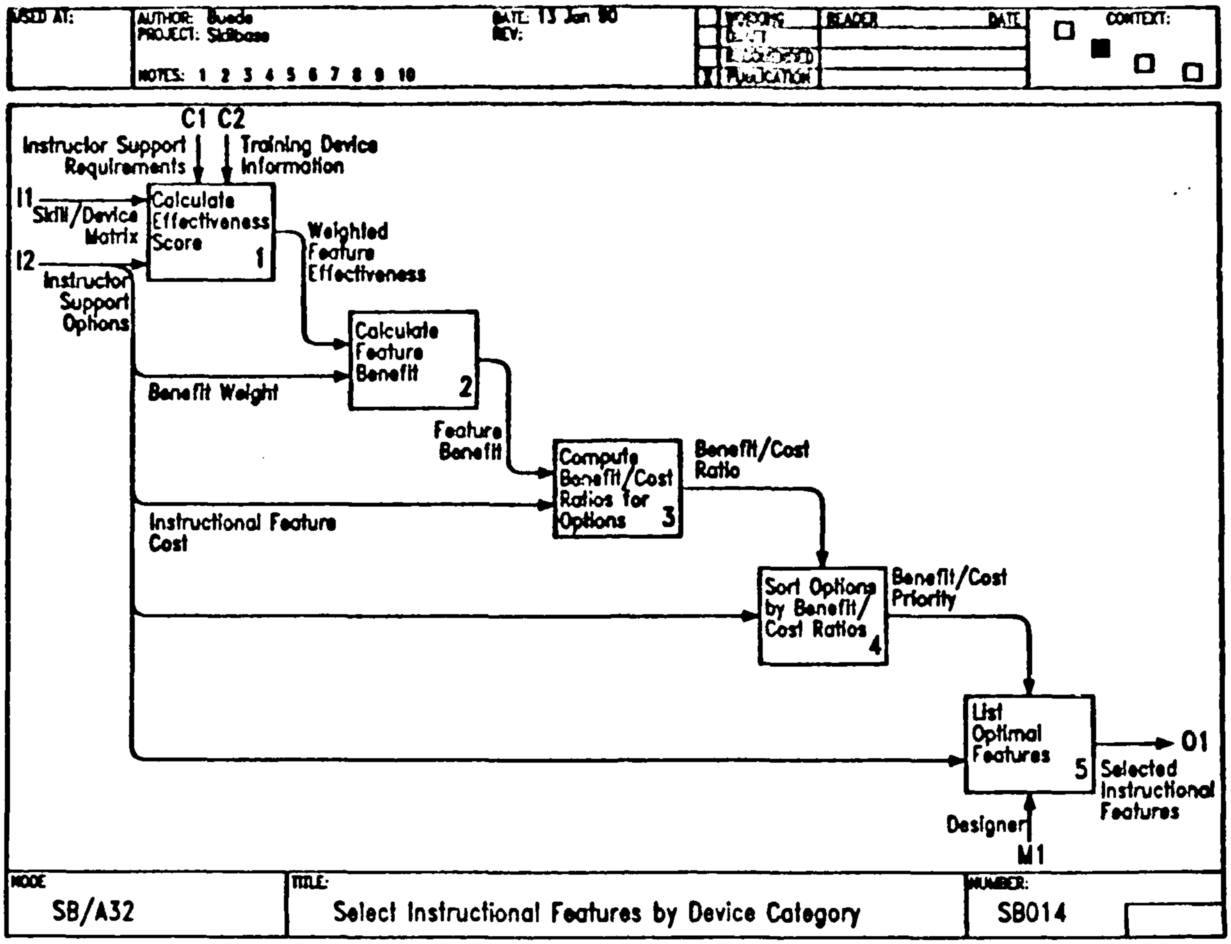


SB/A32: Select Instructional Features by Device Category

This activity identifies, given a development cost, the instructional features that will improve training for the most skills. Instructional features are presumed to influence the efficiency of training rather, represented by the time multiplier of the learning model, than the maximum effect of training or transfer of training, represented by the asymptote. Five major activities compose this tool: An effectiveness score is calculated for each instructional feature; the effectiveness score is converted to a feature benefit measure; a benefit/cost ratio is calculated; instructional features are sorted by benefit/cost ratio; and optimal combinations of features are listed. The output of this activity is a list of feasible instructional features ordered by benefit/cost ratio.

SB/A321: Calculate effectiveness score. This activity determines the effectiveness score by finding for each instructional feature the sum of the skill-group weights for each skill group that requires that instructional feature. The instructional features considered in this analysis are limited by those that are consistent with the capabilities of general training device type being specified.

SB/A322: Calculate feature benefit. This analysis broadens the concept of instructional feature effectiveness to incorporate the likelihood that the feature will be used, expressed as a probability, based on historical usage data. The

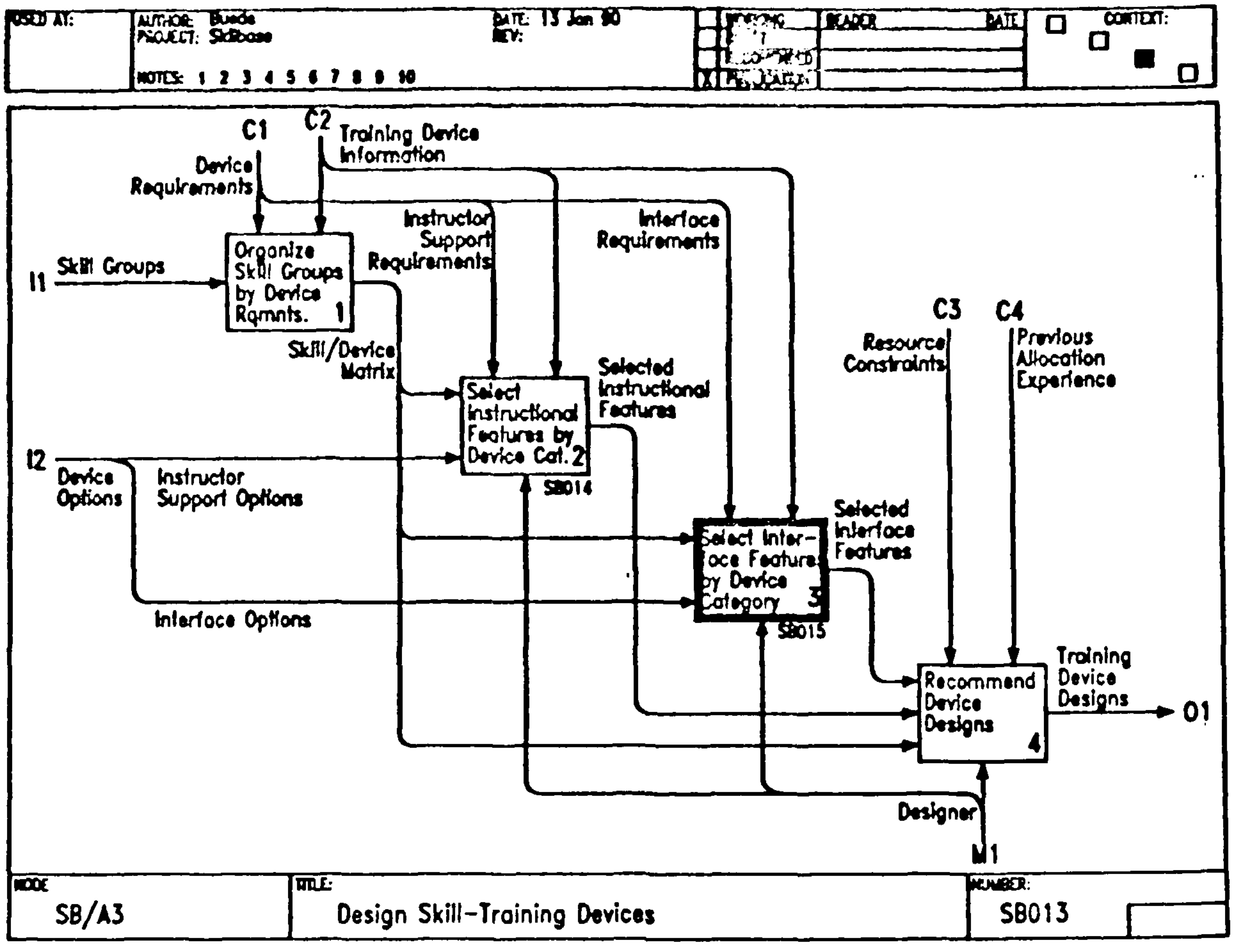


instructional feature benefit is given by the product of the effectiveness score calculated in A321 and an instructional feature weight that reflects the relative usage probability for that feature. The feature benefit may be viewed as the expected proportion of skill groups addressed by an instructional feature.

SB/A323: Compute benefit/cost ratios for options. This process combines the calculated instructional feature benefits with the assessed feature costs, by dividing the benefit by the cost to obtain a benefit/cost ratio.

SB/A324: Sort options by benefit/cost ratios. This activity orders the instructional features according to decreasing benefit/cost ratio. If the features are independent, this order represents the optimal order in which to incorporate instructional features into a training-device design as a function of cost.

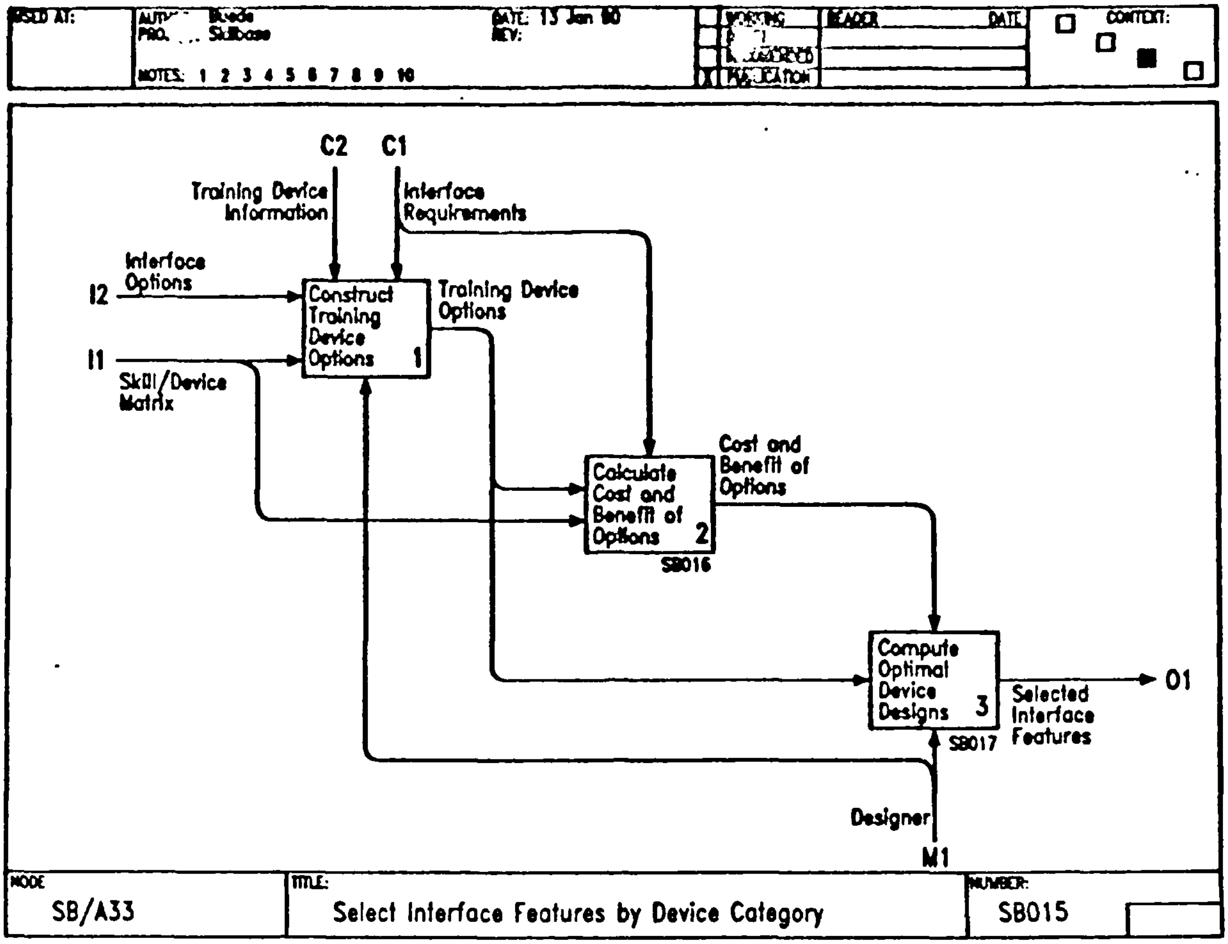
SB/A325: List optimal features. This activity presents the results of the analysis so that the user may determine the instructional features that should be included to meet cost or benefit criteria. The optimal list of features at any cost (or benefit) level is found by adding features to the list in sorted order until the cumulative cost (or benefit) is equal to the criterion level. This activity takes the range of costs and produces as output the set of optimal instructional feature packages for all costs in the range. Included in the output are the cost and benefit of each package.



SB/A33: Select Interface Features by Device Category

This activity consolidates skill interface requirements for the skill groups being considered for a training device with the computational and interface capabilities of the class of training device being designed to produce a design that meets the most critical requirements at the minimum cost. Computational and interface capabilities are assumed to influence the maximum effect of training or transfer of training rather than the speed of learning. The output of this activity is a list of feasible interface options, ordered by benefit/cost ratio.

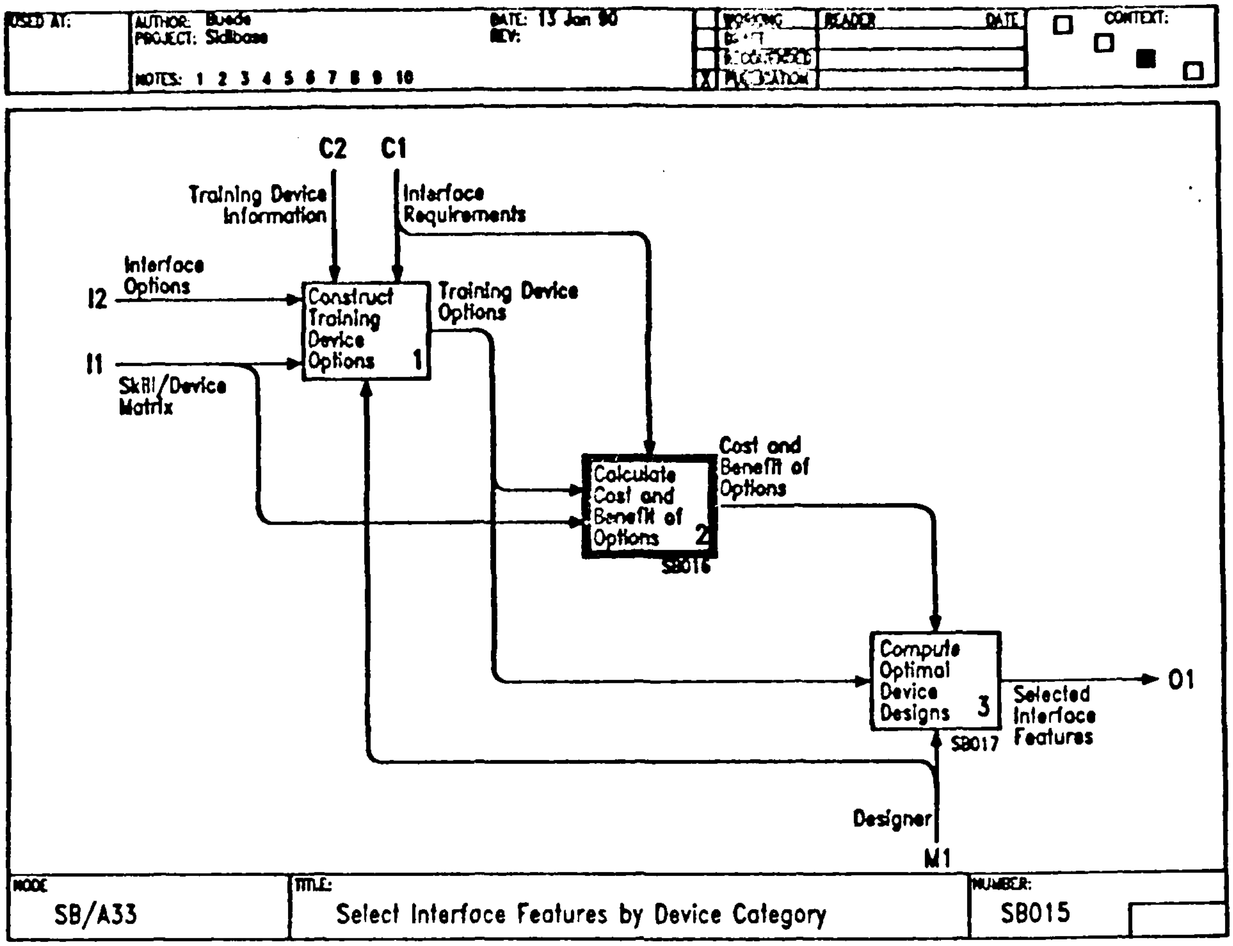
SB/A331: Construct training device options. This activity selects a set of active interface options to be considered in the analysis from the set of all options. If a general-purpose training device is being specified, then the active options are the components of the training device for which options exist. For example, for a microprocessor-based CBI system, these options would include the display controller, the display monitor, video capability, the processor capabilities, and so forth. If a special-purpose training device is being specified, then the options will be determined by the interface dimensions on which the skill groups being considered have interface requirements (from A243). The levels that will be included range from no capability to the maximum requirement on each dimension. The user may modify this choice by selecting or eliminating interface dimensions and specifying the levels of capability on each dimension that will be



evaluated by the analysis. The output of this activity is a set of candidate interface dimensions and levels, with associated technical performance and cost information that are drawn from the data base.

SB/A332: Calculate cost and benefit of options. This activity consists of four steps that establish development costs and training benefits for each option. The costs and benefits are comparable across interface dimensions and are based on the technical performance of the options. Costs are determined from technical performance by an estimation function in the first subactivity. The remaining three subactivities determine benefit by determining skill trainability, calculating a benefit score within each interface dimension, and determining weights that place benefit on a common scale across dimensions.

SB/A333: Compute optimal device designs. This process has three operations. The optimal training-device designs are based upon the incremental benefit/cost ratios of the options. After these ratios are computed, the options are sorted in priority order, and optimal designs are defined for user-specified cost or performance levels. The output of this activity is a set of optimal interface designs at various cost levels. Included in the output are the cost and benefit of each design.



SB/A332: Calculate Cost and Benefit of Options

This process yields the benefit and cost data needed to compute the incremental benefit-to-cost ratios for the optimization in SB/A333.

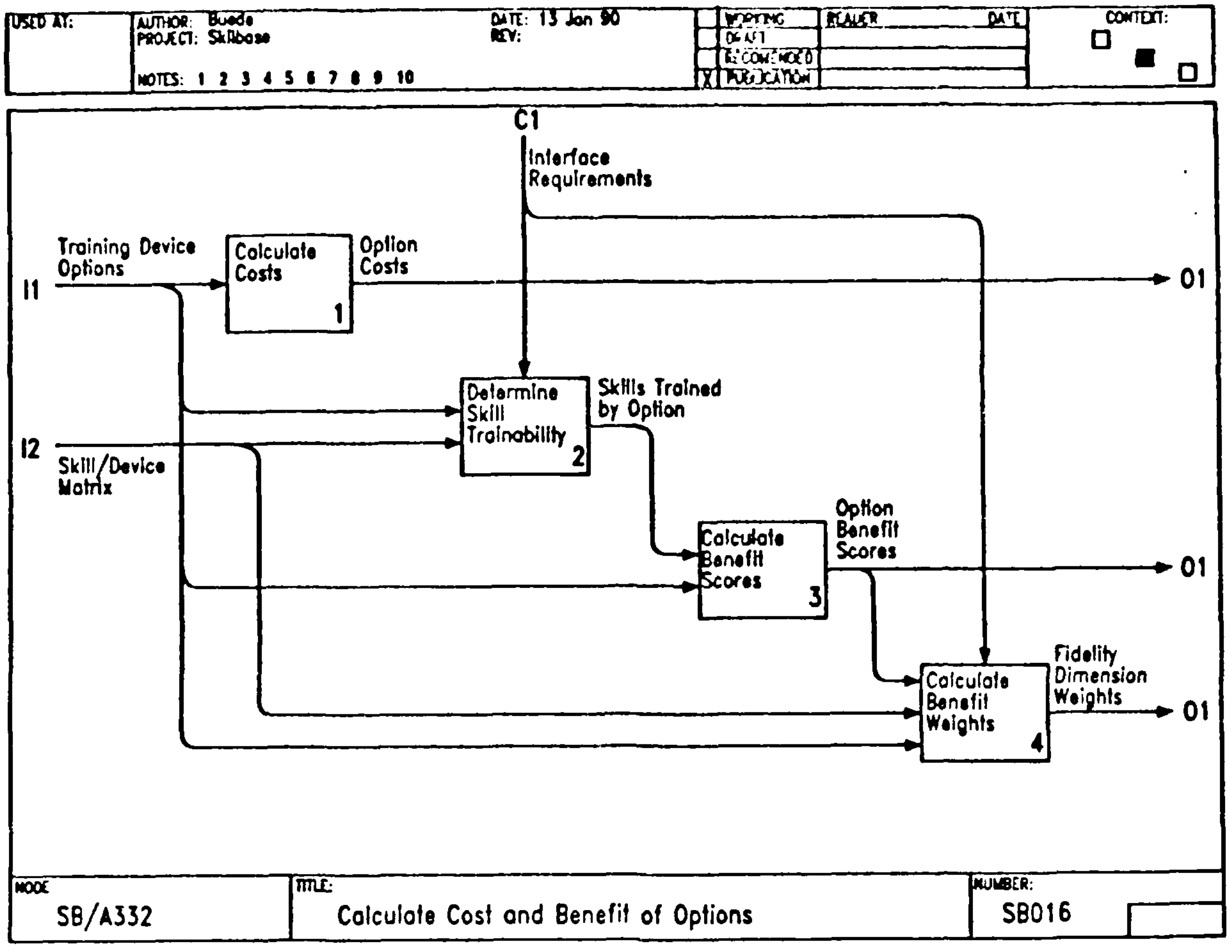
SB/A3321: Calculate costs. This activity addresses the development costs of a training device and is a straightforward calculation from interface dimension data using the cost equations shown below. The cost estimation function is designed so that constant increments of technical performance are more expensive at a high performance level than they are at a low performance level. The cost equations relate the development costs to the technical performance index in the range of options under consideration, as follows:

$$CDEV_{jm}(TP_{jm}) = CMIN_j + (CMAX_j - CMIN_j) * CREL_{jm}$$

where

$CDEV_{jm}$ = the development cost of training device option m on interface dimension j,

$CMIN_j$ = the development cost of the least capable training device option on interface dimension j,



$CMAX_j$ = the development cost of the most capable training device option on interface dimension j,

$CREL_{jm}$ = the normalized development cost of training device option m on interface dimension j, and

TP_{jm} = the technical performance index of training device option m on interface dimension j.

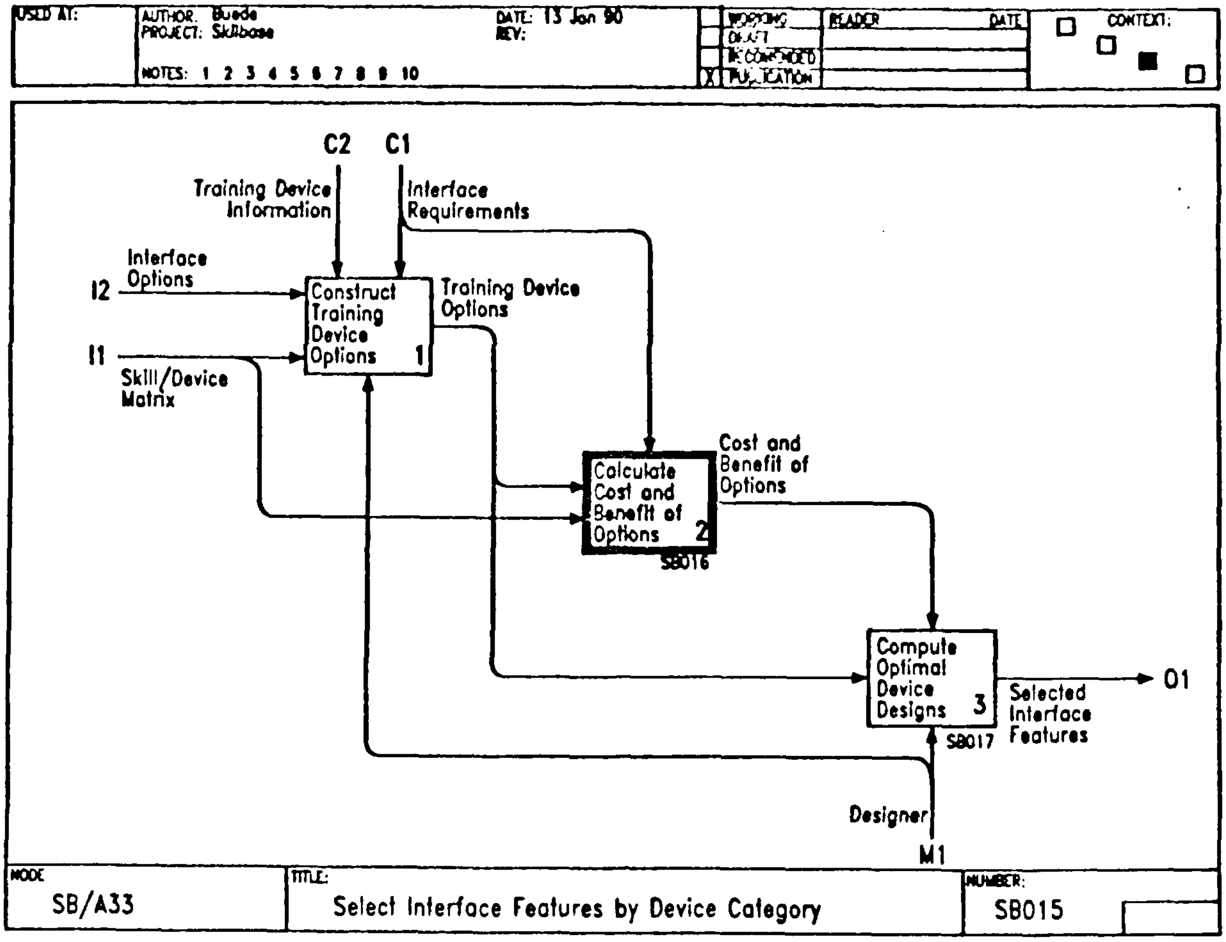
$CREL_{jm}$ is calculated from the relative technical performance ($TPREL_{jm}$) which measures the technical sophistication of each option m on interface dimension j. $TPREL_{jm}$ is also defined on a scale from 0 to 1.0 as a function of the absolute technical performance (TP), and is calculated as follows:

$$TPREL_{jm}(TP_{jm}) = \frac{TP_{jm} - TPMIN_j}{TPMAX_j - TPMIN_j}$$

where

$TPMAX_j$ = the technical performance of the most capable option on interface dimension j,

$TPMIN_j$ = the technical performance of the lest capable option on interface dimension j, and



$TPREL_{jm}$ = the normalized (between 0 and 1.0) technical performance of training device option m on interface dimension j.

TP_{jm}, $TPMIN_j$, and $TPMAX_j$ are all part of the existing data base on training device options.

To compute the normalized development cost, the following equation is used:

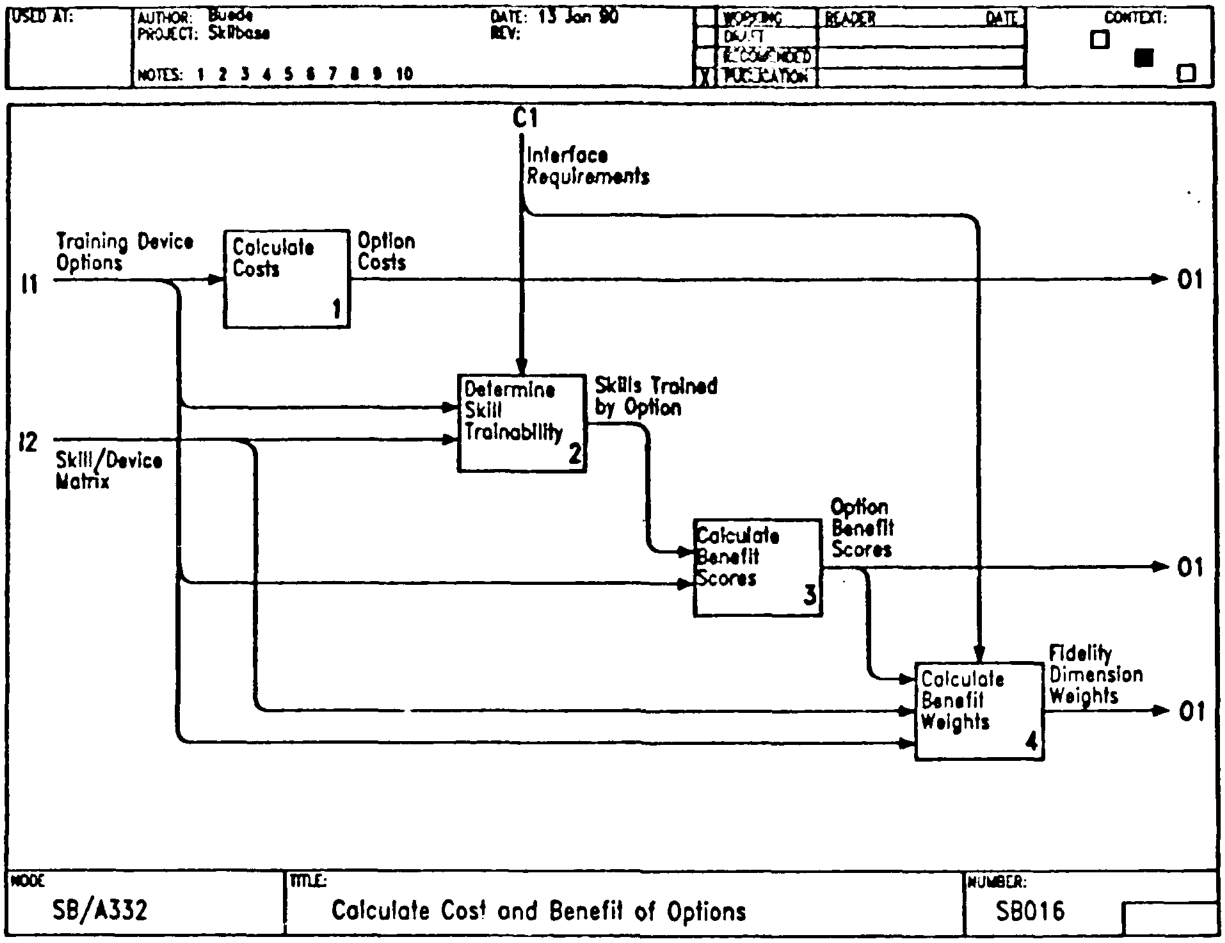
$$CREL_{jm} = -(1/E_j)\ \ln[1 - TPREL_{jm}\ (1 - \exp(E_j))]$$

where

E_j = a constant that describes the interface dimension.

This function has a property that technology becomes more costly as the constant exponent (E_j) increases in size.

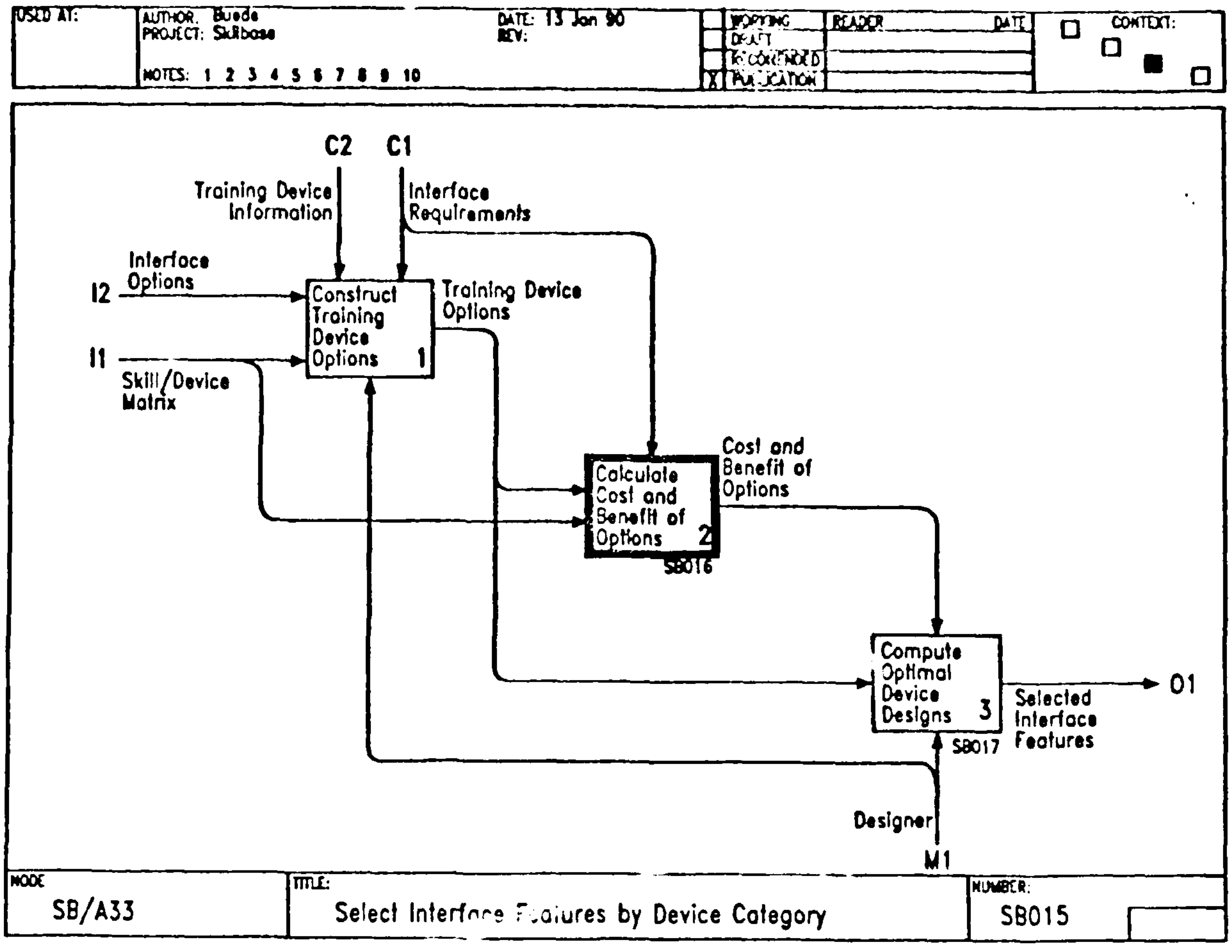
SB/A3322: Determine skill trainability. This is the first step in the calculation of benefits for training device options. This activity examines each option of each interface dimension, and compares the technical performance of that option, TP_{jm}, with the corresponding interface requirements of each skill



group (as defined in A243) being addressed by the training device. The activity records via a three-dimensional skill trainability matrix, TRN_{Sjm}, which skill groups have requirements that can be met by each level of each interface dimension. The output of this process is the three-dimensional matrix (skill groups by interface dimension by level) that enumerates the skill group requirements that are met by each interface level.

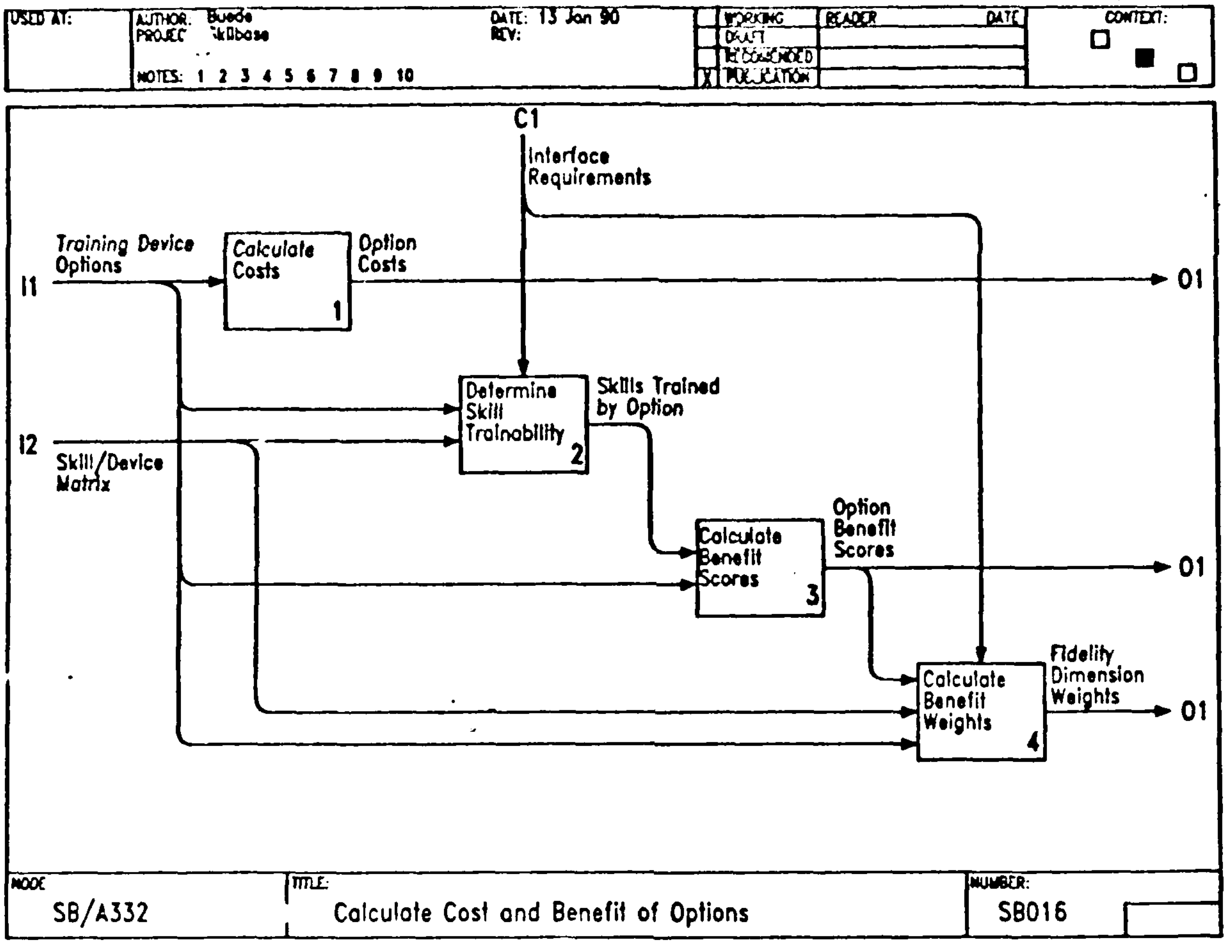
SB/A3323: Calculate benefit scores. This process uses the skill trainability matrix, TRN_{Sjm}, generated in the previous process (A3322) and the skill group importance weights calculated in A213 to calculate the benefit score of each option. The benefit score is defined to represent the relative benefit of an option within its interface dimension. For all options within an interface dimension, the benefit scores represent the weighted ratio of skills that can be trained within that interface dimension. These benefit scores fall between 0 and 1.0; where 0 represents the inability to train any skills and 1.0 represents the ability to train all skills within that dimension.

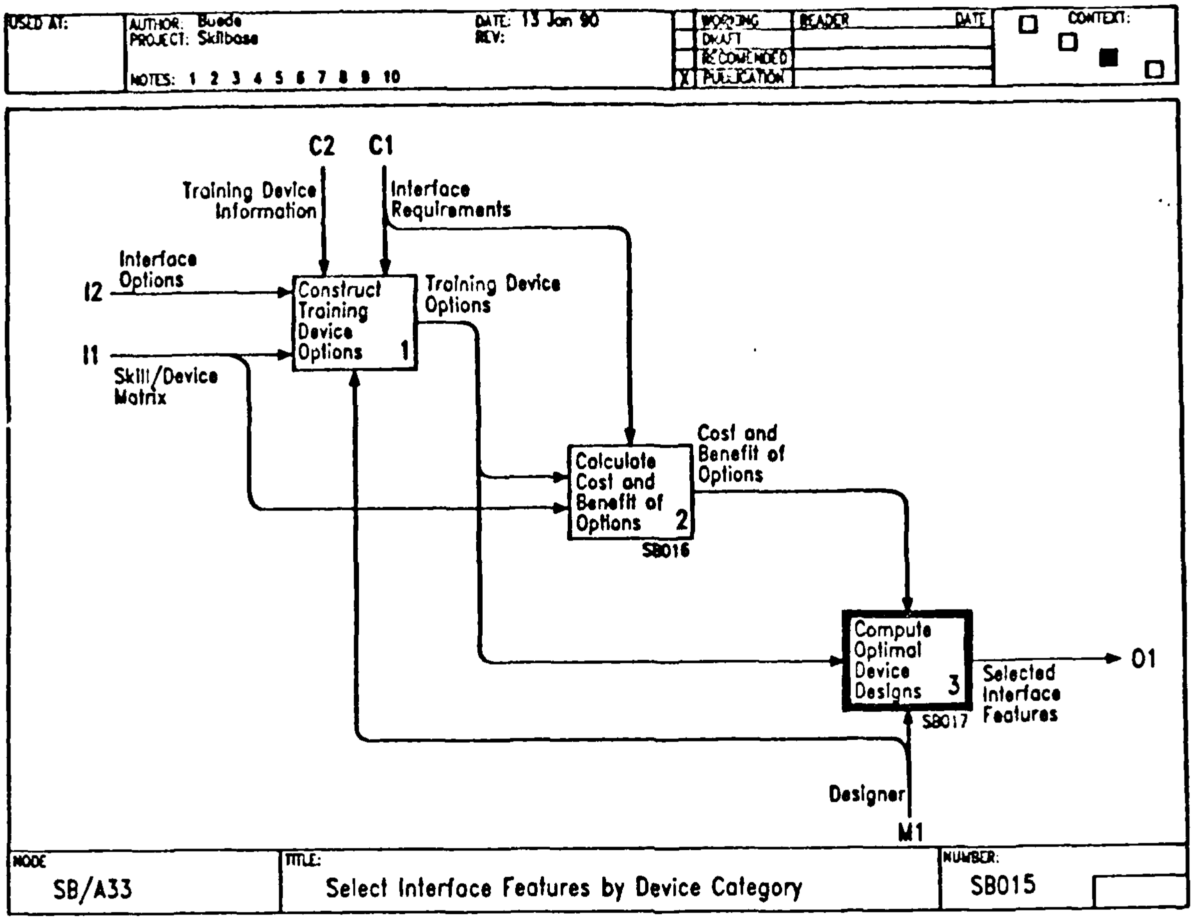
The benefit scores of each interface dimension level are calculated by summing the skill-group weights for all skill groups that have requirements that are met by the specific level. That is, skill-group weights are placed in the skill-group trainability matrix for all cells in which the skill group was trainable.



The resulting matrix is then summed over skill groups to produce a two-dimensional (interface dimension by level) benefit matrix.

<u>SB/A3324: Calculate benefit weights</u>. The interface dimensions receive a weight that reflects the extent to which important skill groups require high technical performance on an interface dimension. The interface dimension weights place benefit on a common scale across interface dimensions. Each of the skill-group requirements is multiplied by the corresponding skill-group weight, and the resulting values (which are two-dimensional, skill group by interface dimension matrix) are summed across skill groups. These interface benefit weights are then normalized to sum to 1.0 to maintain scale relationships among benefit values.


USED AT:
AUTHOR: Buede
PROJECT: Skillbase
DATE: 13 Jan 90
REV:
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
X PUBLICATION
READER
DATE
CONTEXT:
C1
Interface Requirements
Training Device Options
I1
Calculate Costs 1
Option Costs
O1
Determine Skill Trainability 2
Skills Trained by Option
I2
Skill/Device Matrix
Calculate Benefit Scores 3
Option Benefit Scores
O1
Calculate Benefit Weights 4
Fidelity Dimension Weights
O1
NODE: SB/A332
TITLE: Calculate Cost and Benefit of Options
NUMBER: SB016

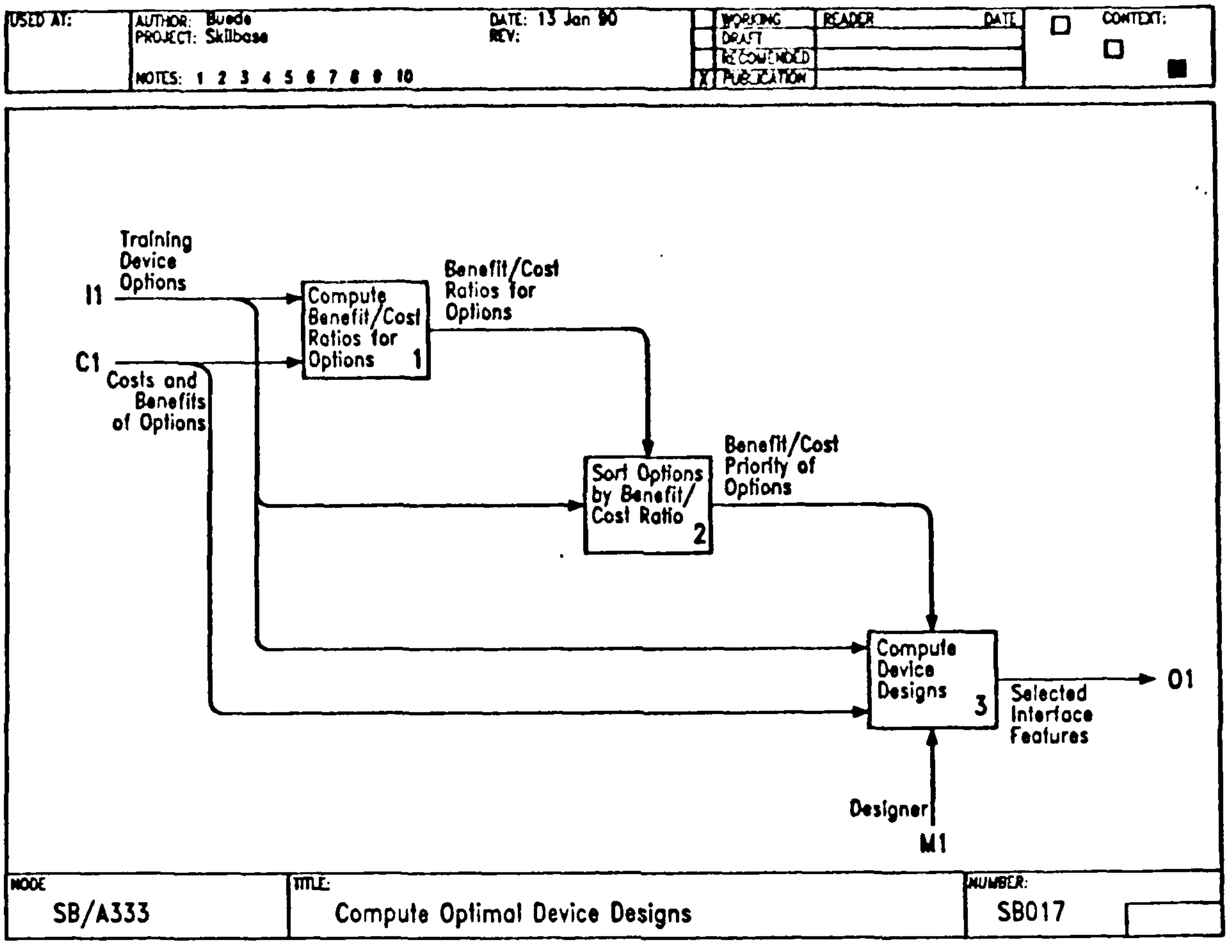


SB/A333: Compute Optimal Device Designs

This process assembles the device interface-dimension levels based upon the incremental benefit-to-cost ratios to attain these levels. It uses this information to determine the optimal training device design at any user-specified level of development cost or benefit. These designs may be evaluated further by using them as inputs to the allocate training activity to determine which option meets the training requirements at the least cost.

SB/A3331: Compute benefit/cost ratios for options. This activity uses the cost and benefit data from the previous major process (A332). The weighted incremental benefit/cost ratio of a level on an interface dimension is calculated by comparing the costs and benefits of that level to the costs and benefits of the previous level (levels are ordered by technical performance). Specifically, the incremental benefit/cost ratio is obtained by dividing the incremental benefit by the incremental cost. This quotient is then multiplied by the appropriate benefit weight to obtain a figure that is comparable across dimensions.

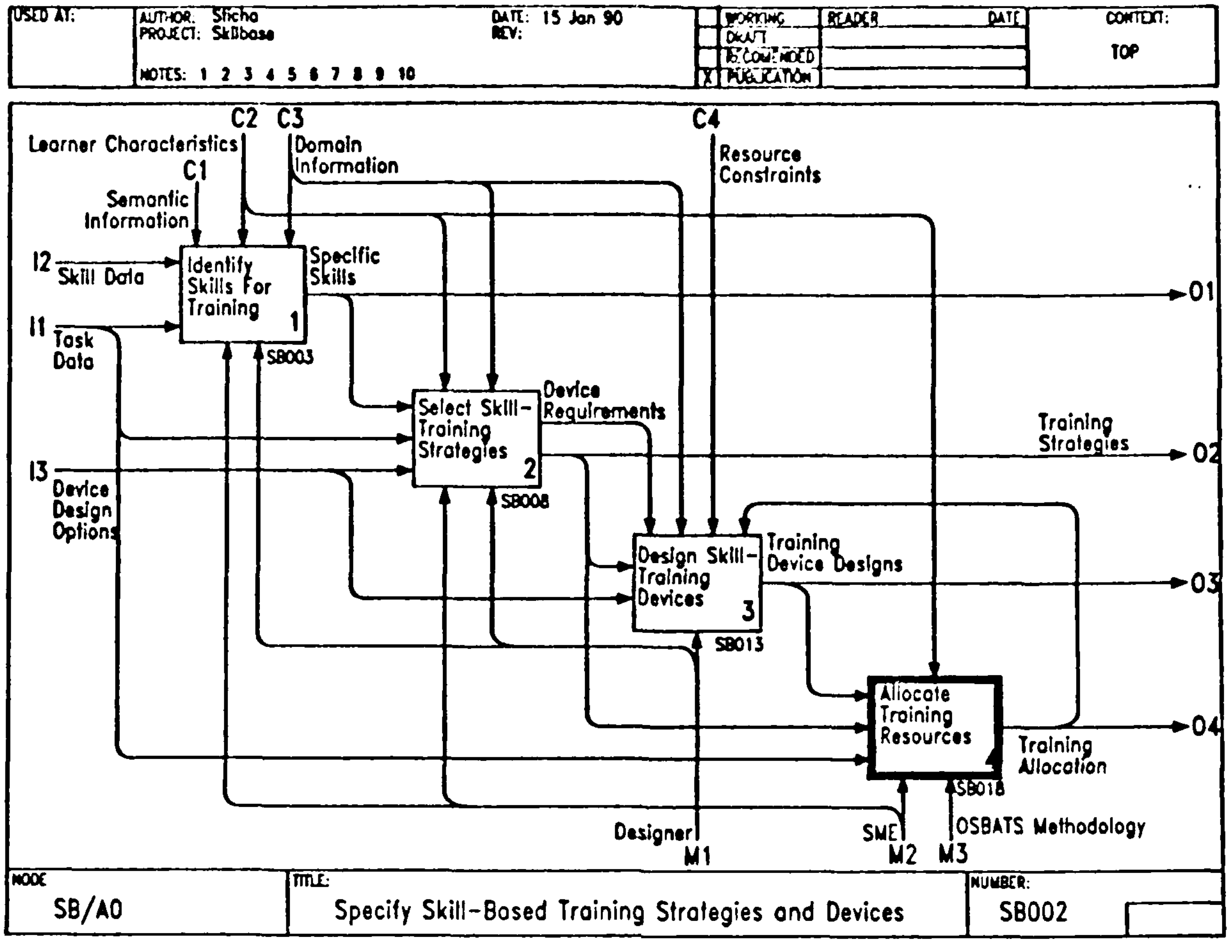
Before the options can be sorted by their benefit-to-cost ratios, these ratios must be guaranteed to be decreasing within each interface dimension. This is done by dropping any level from consideration that is not cost-efficient within that



dimension. When only cost-efficient options remain, the incremental benefit/cost ratios are recalculated from the remaining options.

<u>SB/A3332: Sort options by benefit/cost ratios</u>. Because the interface dimensions have been constructed to be independent building blocks of a training device (to the extent that this is possible), they can be prioritized solely on the basis of the incremental benefit/cost ratio. The output of this activity lists the options on all interface dimensions in order of decreasing benefit/cost ratio.

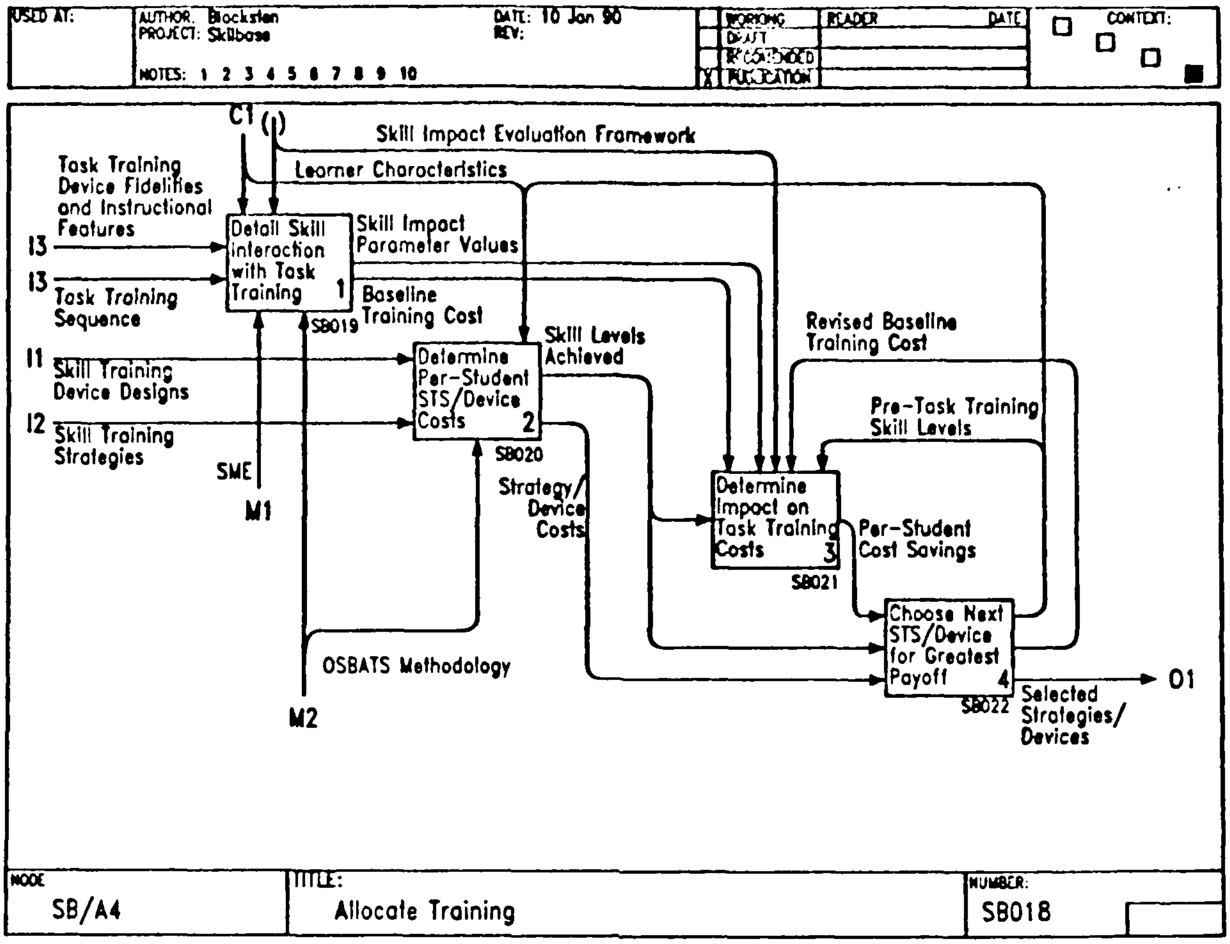
<u>SB/A3333: Compute device designs</u>. This activity presents the results of the analysis so that the user may determine the interface options that should be included to meet cost or benefit criteria. The optimal list of features at any cost (or benefit) level is found by adding options to the list in sorted order until the cumulative cost (or benefit) is equal to the criterion level. This activity takes the range of costs and produces as output the set of optimal interface feature packages for all costs in the range. Included in the output are the cost and benefit of each package.



<u>SB/A4: Allocate Training</u>

This activity selects the previously defined STSs and associated devices that minimize the total cost of student training. Cost is minimized using a sequential optimization algorithm. At each stage of the algorithm a payoff matrix is constructed showing the costs to execute the STSs on various devices and the cost savings that will be realized in task training by prior skill training. The difference between task training cost savings and STS/device training costs is the total savings for that STS/device combination. The STS/device yielding the greatest total savings is selected as the next STS/device to be included in skill training. When no STS/device remains offering greater savings than costs, the allocation is completed.

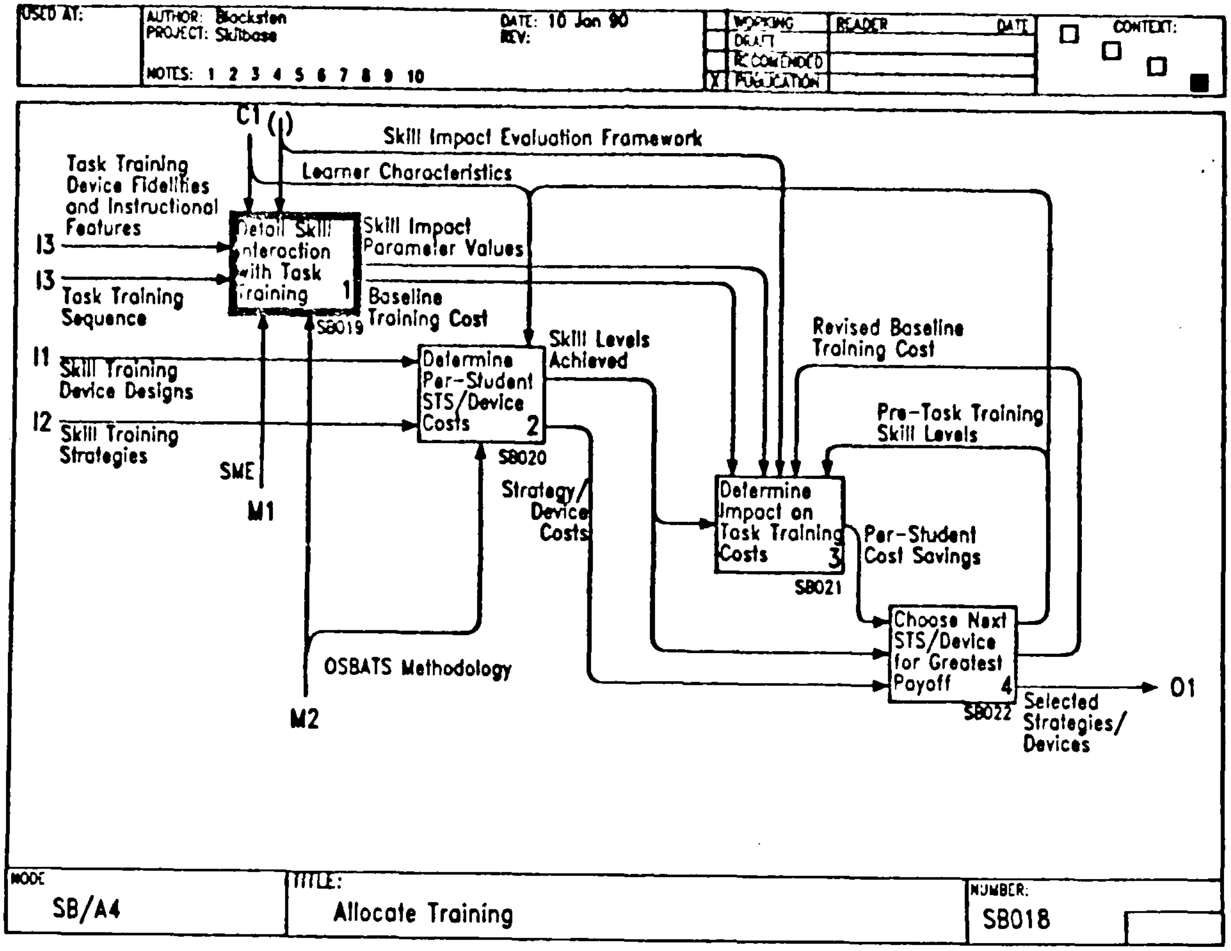
<u>SB/A41: Detail skill interaction with task training</u>. In order to determine the impact of skill training on subsequent task training, it is necessary to address the complete student training program, encompassing the tasks to be trained, the devices to be employed, and the learning curves versus cost expenditures for these devices. In this activity, these factors are used to construct a skill impact evaluation framework to be employed later in the optimization. The precise nature of this framework will depend on the form and quality of skill-to-task transfer research data.



SB/A42: Determine per-student STS/device costs. OSBATS device costing methodology is used to determine per-student costs of the candidate STSs on applicable devices. Skill learning curves are constructed for each device based on interface and instructional features. The training time to bring the student to criterion for the skills addressed by the STS is determined for each STS/device combination. This training time is used as the basis for STS/device costing. The per-student cost is based on the development cost of the device plus the fixed and variable costs associated with training the student for the required training time.

SB/A43: Determine impact on task training costs. Task entry performance is a function of the skill levels attained prior to task training, and on tasks trained earlier in the student training program. In addition to effecting increases in task entry level performance, skill training may cause an acceleration in the task learning rate. Depending on the precise skill impact evaluation framework employed, these benefits will be considered explicitly or implicitly.

SB/A44: Choose STS/device for greatest payoff. The total payoff for a candidate STS/device combination is the total cost savings for all the tasks to be trained, less the cost of the STS/device training. These payoffs are computed for each applicable STS/device combination, and that STS/device with the greatest payoff is included in pre-task skill training. If no STS/device yields a positive payoff, then the training allocation process is concluded.

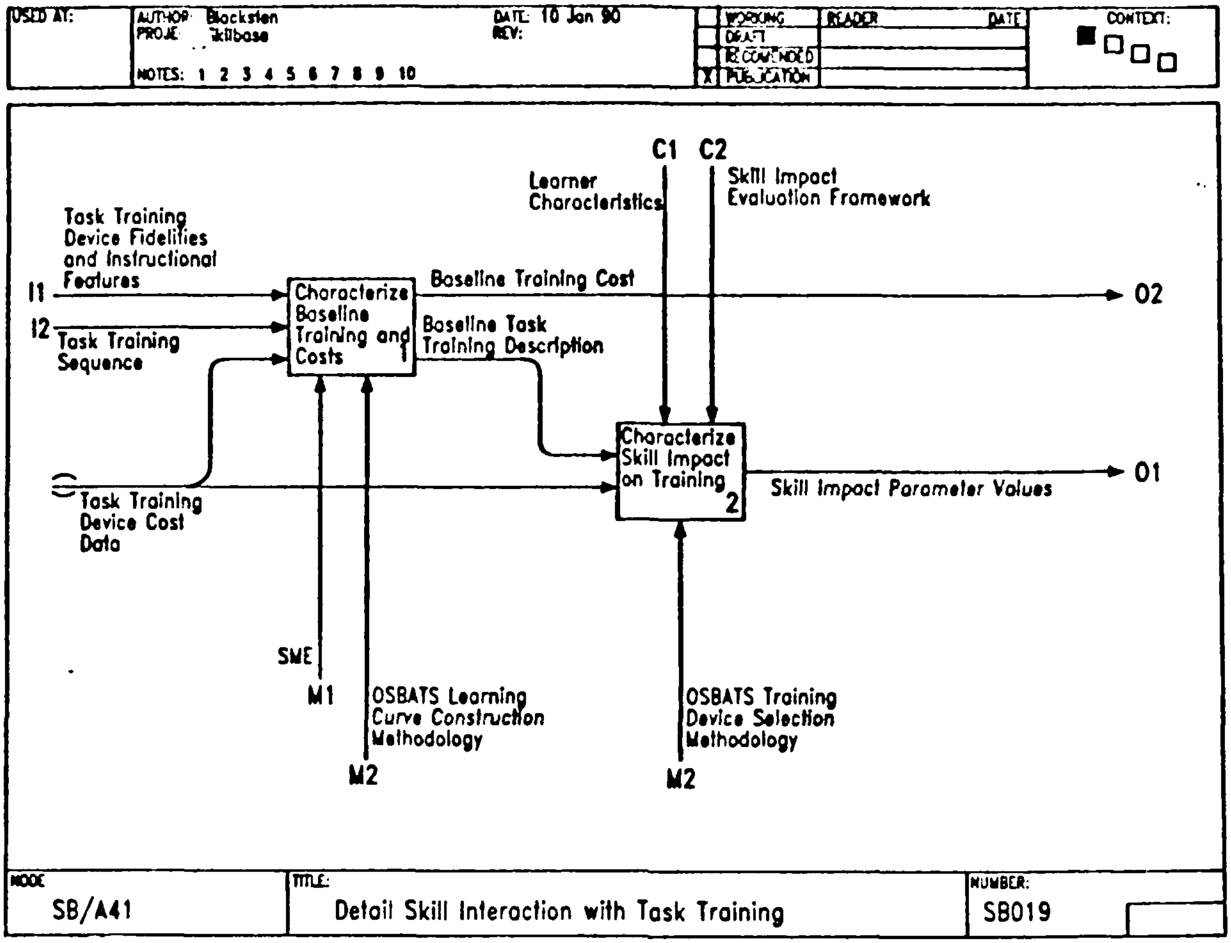


SB/A41: Detail Skill Interaction with Task Training

This activity consists of two steps: first, characterize the optimal task training program without skill-based training. Second, structure the way in which this training program will be impacted by improved initial student skills.

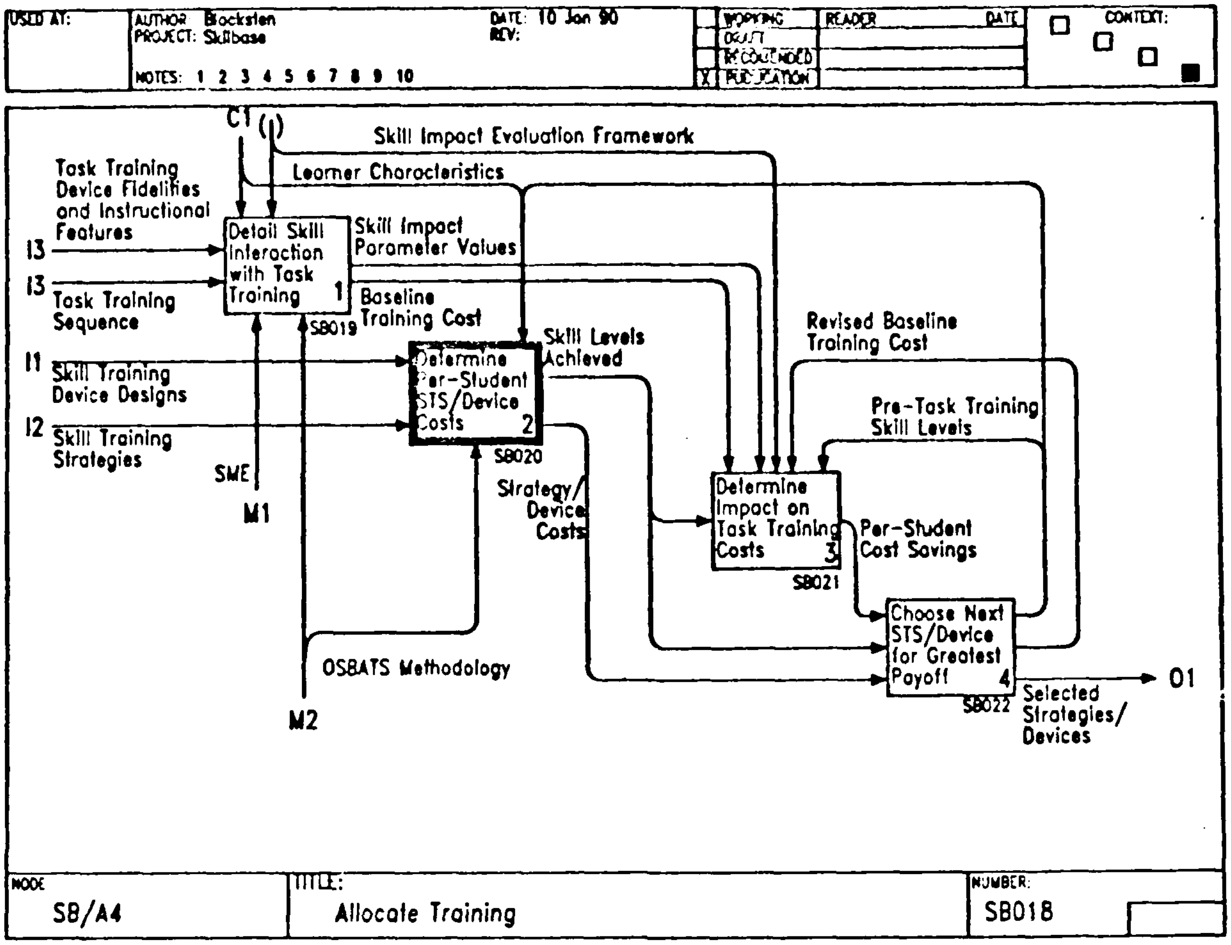
SB/A411: Characterize baseline training and costs. Task learning curves for existing task training devices may be available from empirical research, while those for yet-to-be fielded training devices may be estimated using the learning curve construction methodology developed for OSBATS. This latter methodology employs indexes of acceptable device fidelity, elicited from SMEs for each task. Learning curves and transfer functions are employed to estimate learning rates and asymptotes on training devices with greater or lesser fidelities, and with selected instructional features. (See Sticha, et. al., 1988.)

The sequencing of task training and training device employment may be specified by the user, or may be optimized using the OSBATS training device selection methodology (Sticha, et. al., 1988). The prescribed sequence of tasks and devices, and the prescribed performance levels at which device transitions are made is then "canned" for efficient further reference. The level of detail saved will depend on the precise nature of the skill impact evaluation framework. At the one



extreme, only the training times and associated costs would need to be saved, whereas, at the other extreme, entire learning curve formulas would be saved.

SB/A412: Characterize skill impact on training. The way in which skill impact on task training is assessed will depend on the skill impact evaluation framework selected. That framework will be tailored to the nature and quality of skill-to-task research data and the nature of SME involvement. The framework will, in any case, require the assignment of parameters, e.g., task learning curve parameters, or skill/task importance weights. In this activity those parameters will be quantified based on information developed in SB/A411.

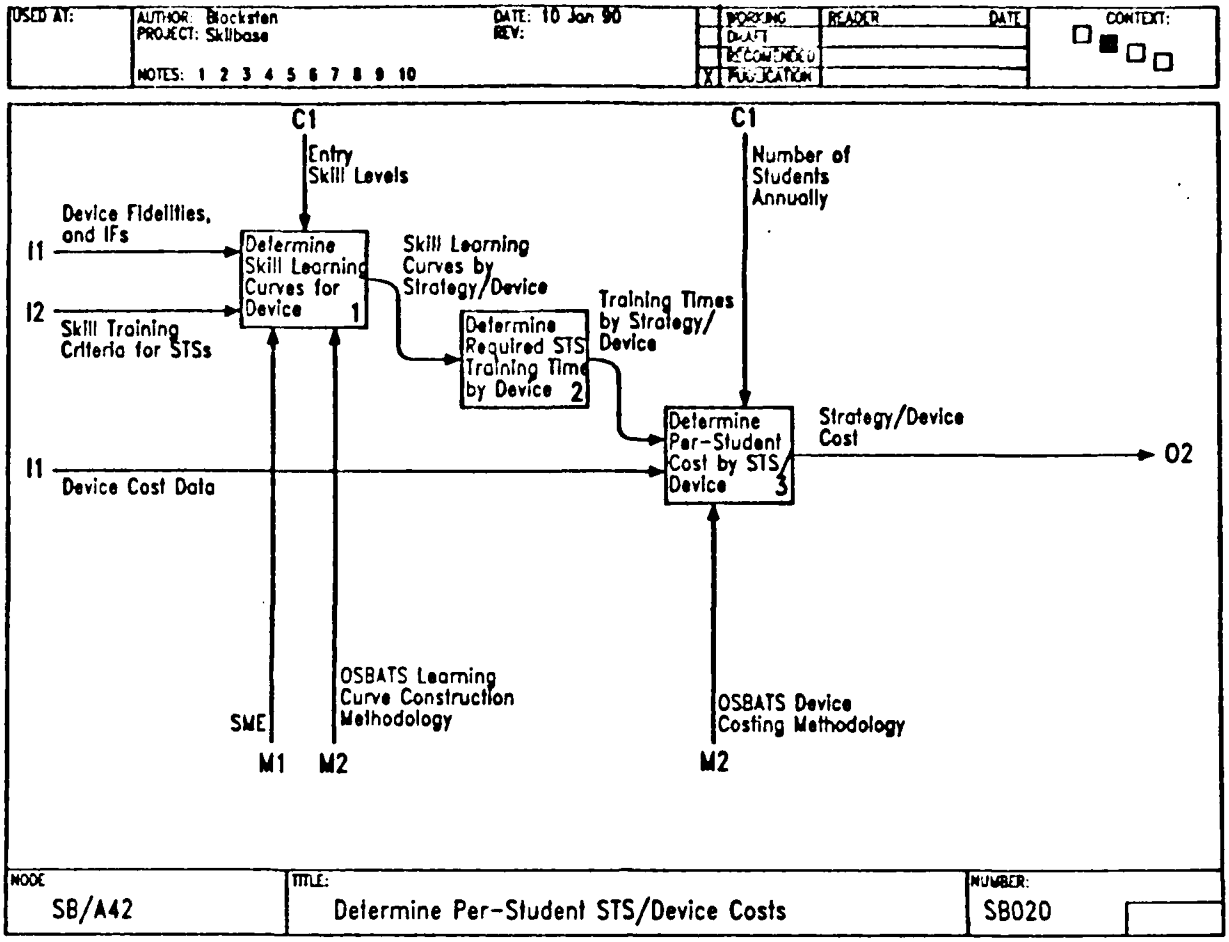


SB/A42: Determine Per-Student STS/Device Costs

To each STS are associated criterion levels for certain skills. To achieve these criterion levels, different amounts of training will be required, depending on the device employed. For each applicable STS/device combination these training times are determined and the associated cost of device employment calculated. Although fairly informal estimation methods may be employed, a more formal procedure, as outlined below, is preferred.

SB/A421: Determine skill learning curves for device. Skill learning curves are constructed for each applicable device, using empirical research results or OSBATS methodology. The latter methodology relies on SME judgments to provide fidelity requirements for various levels of skill acquisition, and then employs a mathematical model to estimate learning rates for the training device, based on the fidelity levels and instructional features of that device. The resulting performance function $P(t;s,m,a_r,c,k)$ expresses the skill level achieved after training for time t. The function involves parameters s, m a_r, c, and k, identified as below. In OSBATS, the learning curve was formulated as

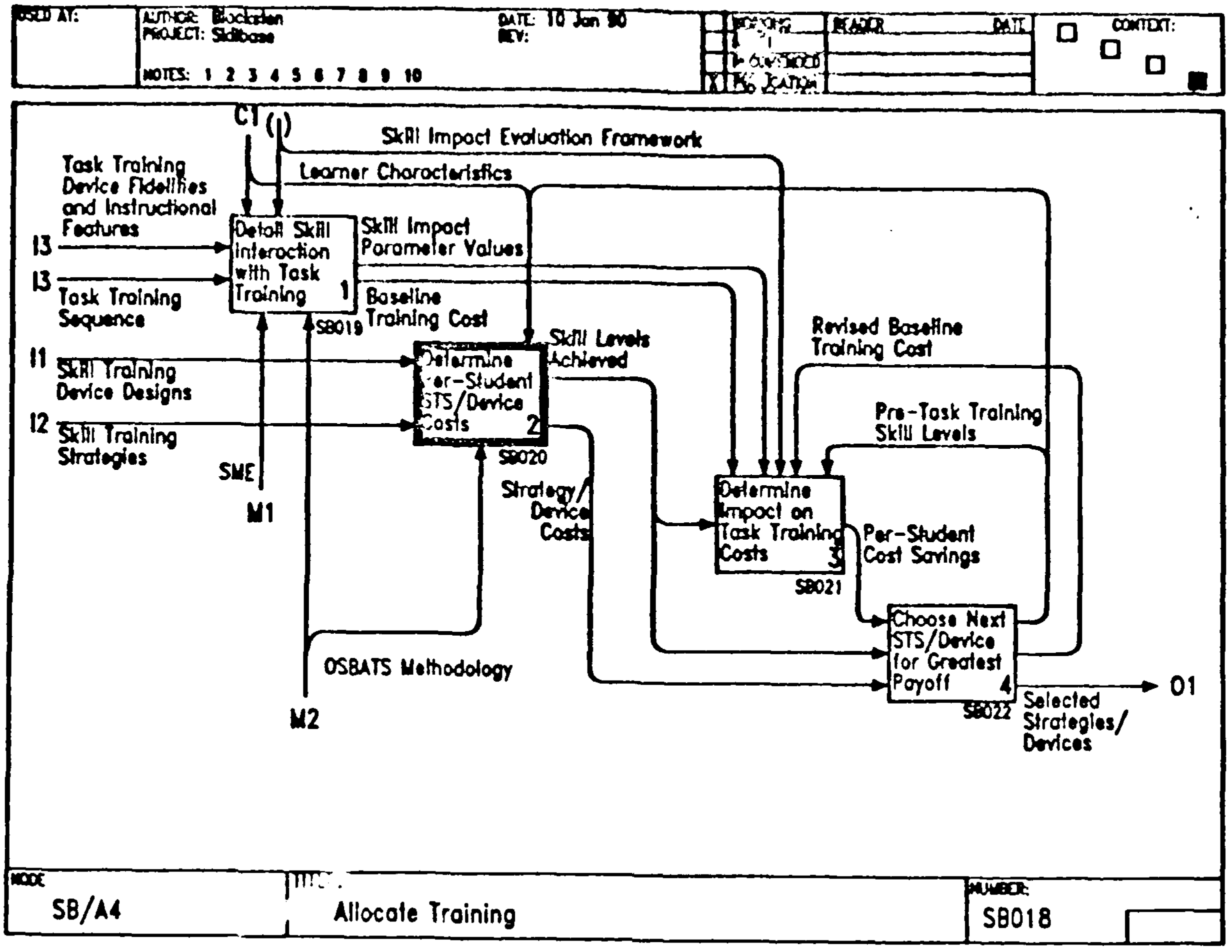
$$P(t) = a_r \{1 - [1 + mc(s+t)]^{-k} \}.$$



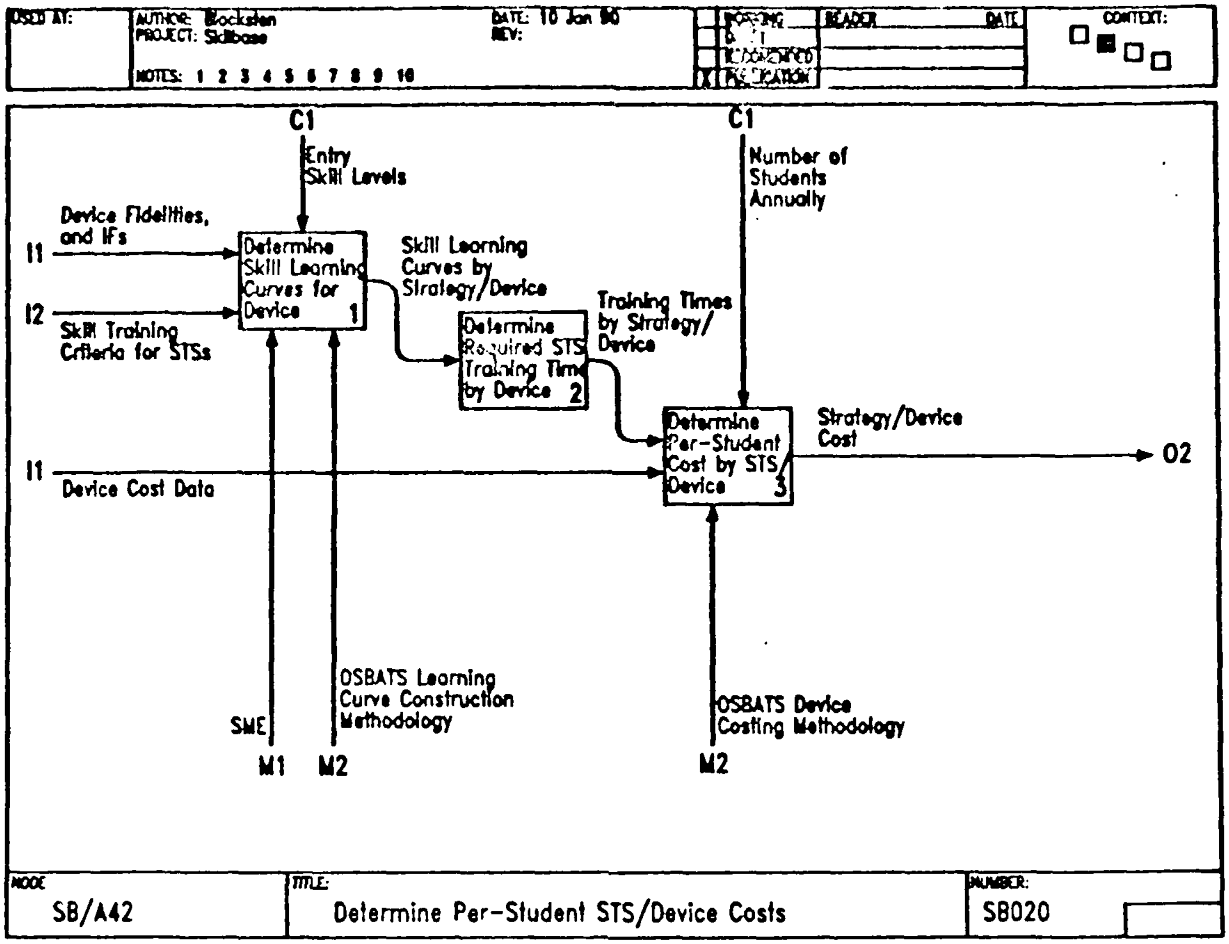
k determines the basic learning curve shape. m is a time multiplier, effecting a compression or expansion of the learning curve along the time axis. c is simply a time scaling constant. The transfer ratio, a_r, is a function of the medium fidelity levels $\{r_i\}$ in each of the different fidelity dimensions, i. The OSBATS methodology for determining a_r also employs SME estimates of required fidelity levels $\{R_i\}$. In addition, an adjustment constant x is employed to calibrate the SME's estimates. The algorithm for determining a_r may also involve constants $\{f_i\}$ relating the limits to fractional degradation in transfer do to poor device fidelity. s is an effective head start time, selected so that P(0) corresponds to actual student entry performance. For the complete procedure for relating these various parameters, see Sticha, et. al., 1988.

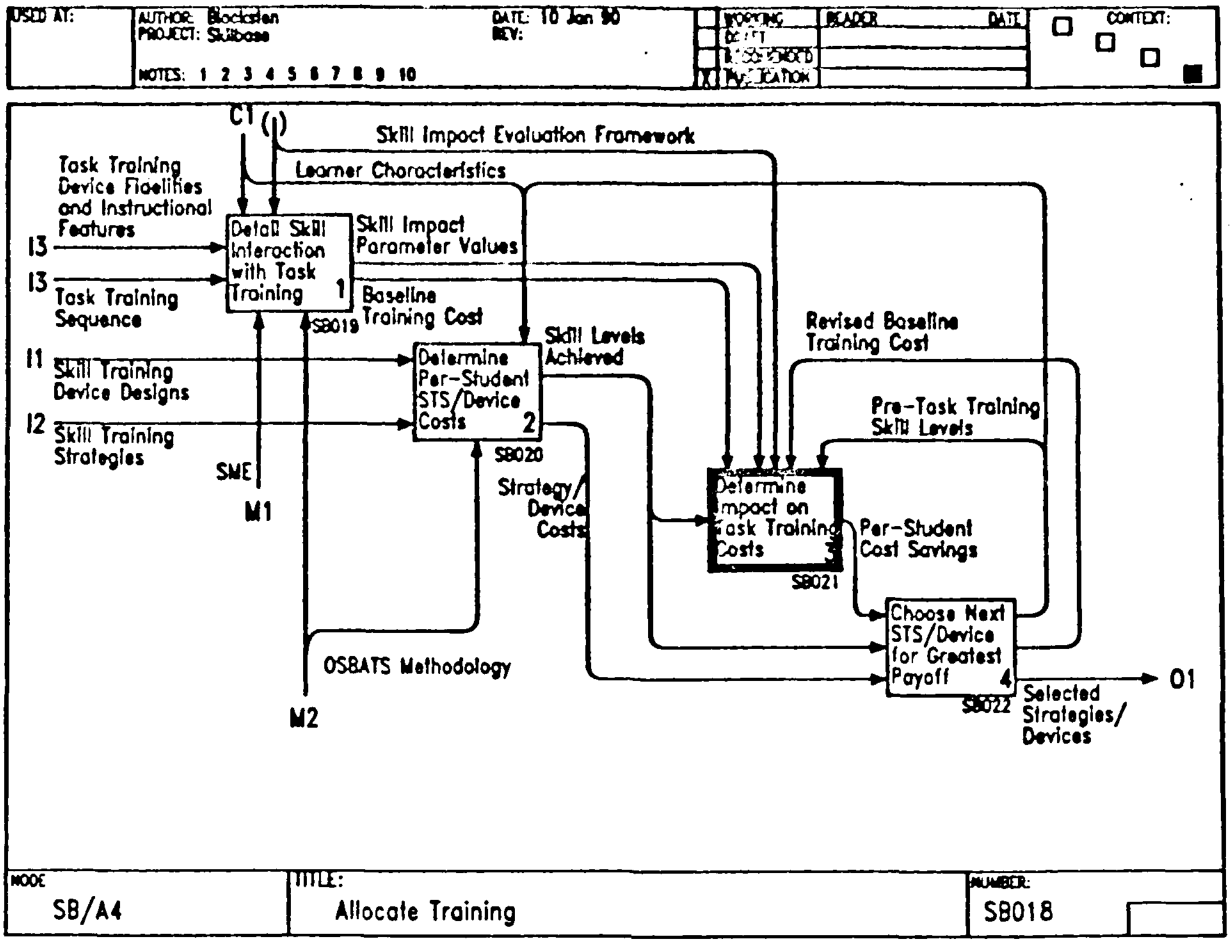
<u>SB/A4222: Determine required STS training time by device</u>. Once the skill learning curves have been constructed, the time required for STS training is determined as the time required to move from entry skill level to the criterion skill levels set for the STS in question.

<u>SB/A4223: Determine per-student cost by STS and device</u>. The per-student cost rate for a particular device is determined from device development and operational cost data, together with knowledge of the demand for that device, a function of the number of students to use it annually, and the amount of time each student is to be trained on it. The actual device costing methodology will be



similar to that adapted by OSBATS (Sticha, et.al., 1988). Typically, the cost curve will be linear with slope $B = (I/L + F)/U + r$, where I represents per device investment cost (i.e., total investment cost assessed across all training devices procured), L = life cycle, F = fixed annual operations cost (per device), U = annual device utilization in student-hours, and r = variable operations cost, per student hour. These parameters are estimated using standard costing procedures.

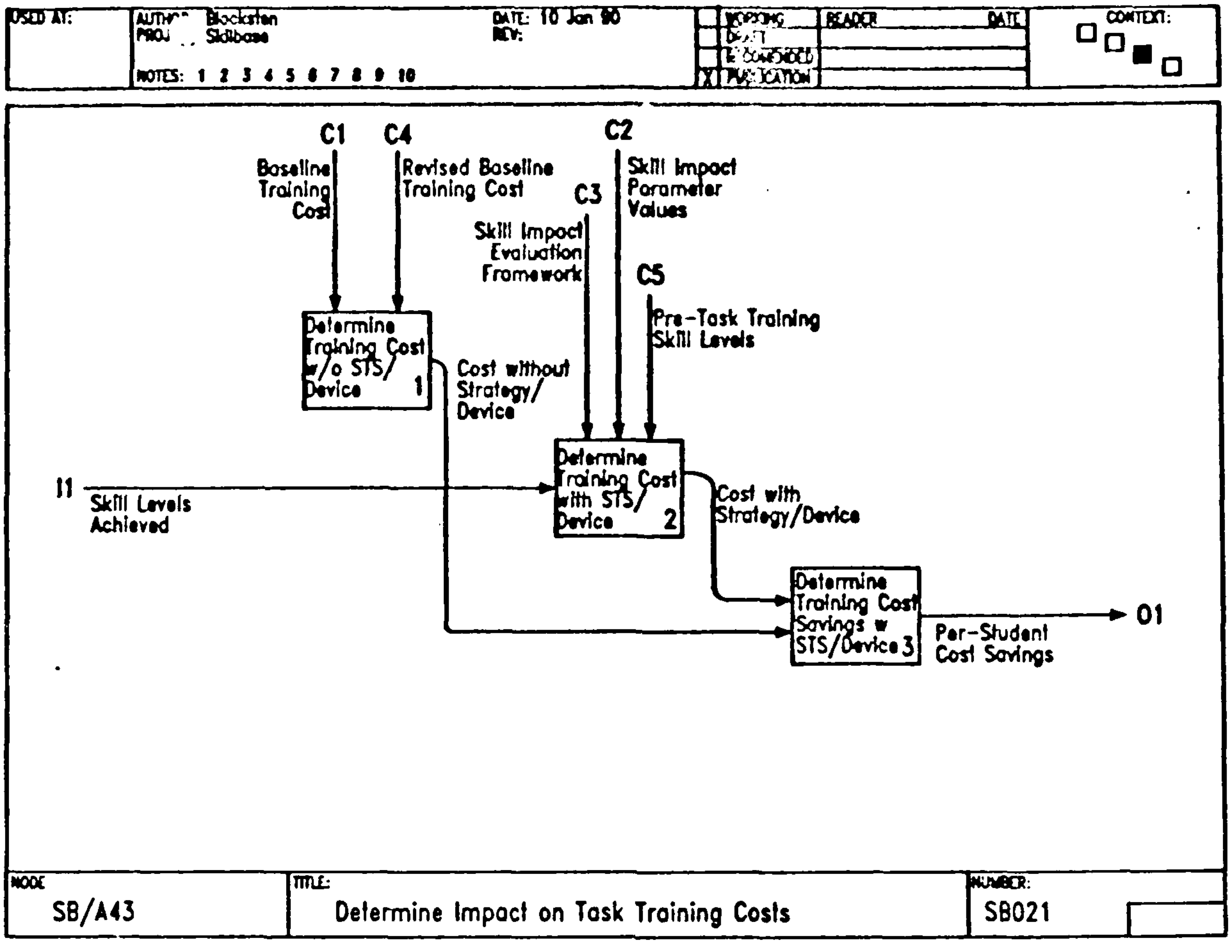

USED AT:
AUTHOR: Blackston
PROJECT: Skillbase
DATE: 10 Jan 90
REV:
NOTES: 1 2 3 4 5 6 7 8 9 10
WORKING
DRAFT
RECOMMENDED
PUBLICATION
READER
DATE
CONTEXT:
C1
Entry Skill Levels
C1
Number of Students Annually
Device Fidelities, and IFs
I1
I2
Skill Training Criteria for STSs
Determine Skill Learning Curves for Device
1
Skill Learning Curves by Strategy/Device
Determine Required STS Training Time by Device
2
Training Times by Strategy/ Device
Determine Per-Student Cost by STS/ Device
3
Strategy/Device Cost
O2
I1
Device Cost Data
SME
M1
M2
OSBATS Learning Curve Construction Methodology
OSBATS Device Costing Methodology
M2
NODE:
SB/A42
TITLE:
Determine Per-Student STS/Device Costs
NUMBER:
SB020



SB/A43: Determine Impact on Task Training Costs

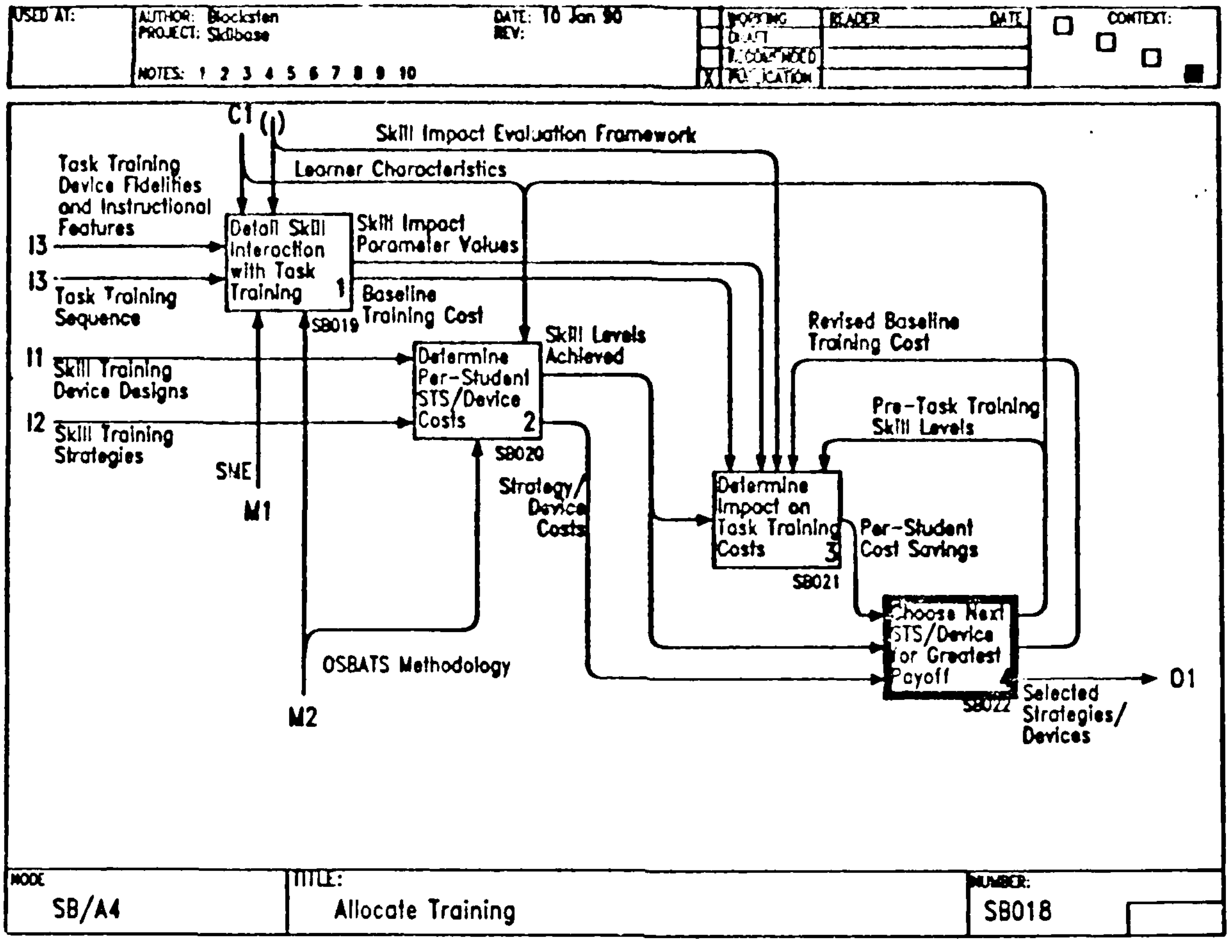
This activity estimates the benefit of adding a particular candidate STS/device combination to those already selected for inclusion. The evaluation consists of three steps. The first is to determine the cost of training all tasks to criterion without skill training with the candidate STS/device combination (but with skill training on any STS/device combinations already selected for inclusion in earlier iterations of the allocation algorithm). The second step is to determine the cost of training if the candidate STS/device is included. The third step is to simply calculate the arithmetic difference.

SB/A431: Determine training cost w/o STS/device. On the first iteration through the skill training allocation algorithm, the cost of training without the candidate STS/device combination is just the baseline training cost estimate developed in SB/A411. On subsequent iterations of the skill training allocation algorithm, the cost will be saved from the preceding visit to SB/A44, and will included the per-student cost of skill training on previously selected STS/device combinations, as well as the cost of subsequent task training. (On each iteration of the algorithm, the total cost of skill training is increased, but is more than offset by reductions in the total cost of task training).



<u>SB/A432: Determine training cost with STS/device</u>. The skill impact evaluation framework developed in SB/A41 is employed at this step to estimate the reduced cost of task training due to time compression, generalization, and reduction of attention requirements for each task as a result of improved entry skills associated with the candidate STS/device. The cost of previously selected STS/devices is included in this estimate, but the cost of the candidate STS/device is excluded. The impact of previously selected STS/devices on learning curves is taken into account in this activity, through revised pre-task training entry skill levels.

<u>SB/A433: Determine training cost savings with STS/device</u>. The net impact that the candidate STS/device would have on per-student task training costs is just computed as the difference between the training cost determined in SB/A431 and that determined in SB/A432.



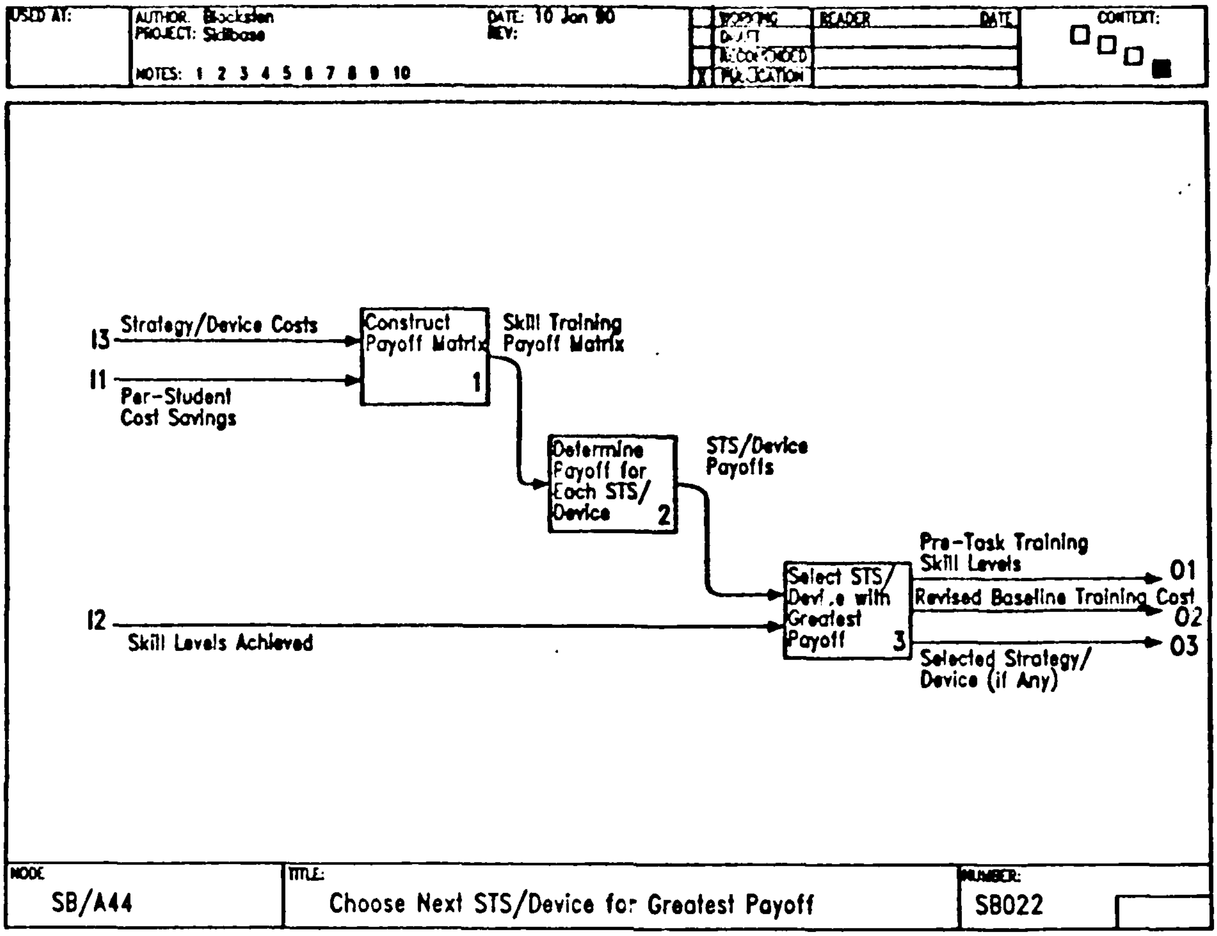
SB/A44: Choose STS/Device for Greatest Payoff.

At each stage of the algorithm a payoff matrix is constructed and used to determine, for each remaining candidate STS/device, the task training cost savings less the STS/device employment cost. The selection of the most effective STS/device is then a matter of identifying that one yielding the greatest payoff.

SB/A441: Construct payoff matrix. A Skill Training Payoff Matrix is constructed by arraying the STS/device per-student costs against the per-student task training savings determined in the preceding activities. An example of the basic payoff matrix is shown at the right.

STS/ Device Combo	Per- Student Cost	Task Training Cost Savings for Task 1	2	3	....	n
1	$370	$100	$50	$0	....	$20
2	$1200	$300	....			
8	$800	....				
9	$700	....				
.	.	....				
.	.	....				

SB/A442: Determine payoff for each STS/device. The information in the basic payoff matrix lends itself to determination of a total per-student task training cost savings realized for each STS/device combination. This savings is



just the sum across all tasks (for the job specialty of the persons in question). The net payoff for each STS/Device is then computed as the total per-student task training savings less the per-student cost of the STS/device, if employed. This gives rise to an expanded payoff matrix, as shown below.

STS/ Device Combo	Per- Student Cost	Task Training Cost Savings for Task 1	2	3	....	n	Per- Student Savings	Payoff =Savings- Cost
1	$370	$100	$50	$0	....	$20	$970	$600
2	$1200	$300	....	....	....	....	$1450	$250
8	$800	....	....	....	....	....	$2000	$1200
9	$700	....	....	....	....	....	$400	-$300
.	.	....	....	....	....	....	.	.
.	.	....	....	....	....	....	.	.

<u>SB/A443: Select STS/device with greatest payoff</u>. The next STS/device that should be selected is simply that one yielding the greatest positive payoff, e.g., STS/device #8 in the example. Revised pre-task skill levels and baseline training costs are then updated and used in the next iteration of the training allocation algorithm. At some iteration, the payoffs of all remaining, unselected STS/device combinations may be negative, indicating that all cost effective STS/devices have been selected and removed from the candidate list. At that point the allocation algorithm is terminated.

DISCUSSION

Skill training as a distinct part of instruction in complex domains has only been attempted in limited applications in which the need is clear, not as a generally prescribed curriculum component. One primary reason that skill training has not become a routine part of the training process is the difficulty of defining and isolating skills. Another is the difficulty of developing skill training strategies, and knowing when skill-based training is more efficient than standard training. There is also the difficulty of specifying the conditions in which skill training will improve mission performance. Underlying these difficulties are the considerable limitations of our knowledge of the interactions between skill and task training options, on the one hand, and skilled mission performance, on the other.

It is difficult to separate the skills from the tasks in which they are required, but the procedures we have developed indicate that it can be done. However, the general applicability of these procedures has not been determined. Their refinement will require application of the methods to a variety of problems. We need to apply the skill-identification and strategy-selection methodology to several domains to get more systematic and comprehensive procedures that can be applied confidently to a variety of job domains by training designers and SMEs.

Two concerns motivated this work: (a) how to produce better trained personnel more efficiently, and (b) how to provide the the most effective training for the least cost. While these concerns seem to be two sides of the same coin, the issues they raise are rooted in different fields of study. The first question leads one to look for instructional principles on which training can be based. It focuses attention on the psychological bases of performance and investigates methods that exploit our understanding of those psychological processes. The second question looks at how instructional methods, having been selected to solve a particular training problem, can be effectively implemented within prevailing technological and cost constraints.

Up to now research on skill-based training has been, with few exceptions, driven by one or the other concern, but not both. Instructional research that has the stated goal of developing "low-cost" trainers have specified the cost constraints only at the most general level (e.g., develop a PC-based trainer). The specific features of the system seem to fall out of the narrowly defined research goals on a particular task, rather than any systematic process. Training-system development projects tend to be driven either by perceived benefits of enhanced technology or cost limitations. Clearly, an optimal training-system development process needs to consider both cost and benefit in evaluating design alternatives.

This project is unique in that it has attempted to merge the two concerns into a single integrated process. The model begins by identifying the goals of instruction and the instructional methods through which those goals can be met.

It then assists the developer in specifying alternative system designs for implementing the instructional methods. In this way the model should produce a solution that satisfies both training and cost objectives.

The dual concerns of the model have led us to consider several different kinds of issues during the model development process. The remaining issues concern the nature of the model from the viewpoint of its simplicity and accuracy, the ability of the model to be used as a decision support system, and the need for future research on skill acquisition and transfer of skill training to task performance.

Modeling Issues

A model must strike a balance between simplicity and validity in its representation of skill acquisition and performance. On the one hand, the model must be able to capture the critical interactions between skills and tasks that makes skill training effective under the proper conditions. On the other hand, an overly complex model may increase the burden for parameter estimation, and may reflect more details about the skill acquisition process than can be justified from the research literature. We began with very simple formulations but ran into numerous difficulties. For instance, by ignoring the fact that skills are inevitably trained to some degree during task training, a very simplistic model overestimated the impact of skill-based training across multiple tasks. As another example, in a first approach to skill-based strategy prioritization, we were unable to guarantee that strategies originally eliminated as inefficient might not become efficient if other skill-based strategies were invoked. Inevitably, such problems led to more complex resource allocation modeling.

We have not detailed the skill impact evaluation framework introduced in the training allocation activity. The precise nature of this framework will depend primarily on the status of skill-to-task transfer research, but must also take into account the time and resources available for additional research, and a careful evaluation of alternate approaches.

Whatever skill-based training evaluation framework is employed, it must address the three ways in which skill-based training can impact total training costs, as discussed in the rationale for skill-based training: (a) time compression, (b) generalization, (c) reduction of attention requirements. In addition, the framework must support reasonable data gathering and estimation procedures. As part of the current research we roughly outlined several evaluation frameworks. We now describe two of these in more detail to indicate the nature and breadth of frameworks for evaluating the worth of skill-based training approaches. Because of the preliminary nature of these frameworks, they are not presented in detail.

Simple Linear Weighting Scheme

In this technique an estimate is made of the importance of constituent skills to learning of, and performance on, a particular task. If skill training increases the entry level of a particular skill within task performance, that increase is multiplied by the importance of the skill to the task to get a measure of value for that skill increase for that task. In the same way the value of the skill increase to each other task in which the skill is used is estimated. A final measure of value for the skill increase is obtained by weighting the value to each task by the importance of that task, perhaps in terms of training dollars. This simple weighting factor approach is then used to compare and select among STS/device candidates.

The advantages of this approach include simplicity, apparent understandability and face validity, easy implementation, and fast computation. A "typical" weighting scheme approach, it may win acceptance based on familiarity. The disadvantages rest in its largely heuristic nature, which makes it difficult to explicate exactly how a skill actually impacts task performance; also, there is reason to believe that this scheme will tend to overstate multiple-task impact by ignoring the skill training that occurs during task training.

Detailed Learning Curve Construction Approach

We investigated a skill impact evaluation framework based on the detailed decomposition of task learning curves into constituent skill learning curves. We assumed that, during training, each increment of student time is partitioned among the constituent skills and the residual task-specific component, which is also accorded an independent learning curve. The fraction of time apportioned to a particular component is made to depend both on the importance of that component and on the "deficit performance" of that skill, i.e., the deviation between current and desired performance. The learning accomplished on a particular task component is then a function of the total time devoted to that component from the start of training; the cumulative time devoted to training one component will be less than the total time involved in training the task, since time is split among the constituent components. If skill training increases the entry performance on a particular skill within a task, then the learning rate on that component will be reduced, while that on the other component skills will increase. This occurs naturally as student attention is focussed most on the least well mastered task components. In consequence, total task performance will increase more quickly. Upon reaching task criterion performance, the level of skill performance will be somewhat higher than would be the case had no prior skill training been undertaken. This increase in skill performance will be transferred to the next task in the training sequence, thereby causing a subsequent acceleration in the training of that task. In this way the multiple task generalization is handled, without overestimating its impact. In addition to dealing with time compression and generalization, the framework can be extended to account for attentional overload.

The primary advantage of the learning-curve based approach is its explicit mathematical description of the linkage between skill and task performance. This makes it easy for the mathematically-trained reader to quantitatively understand the three ways in which skill-based training can impact total training costs. Disadvantages include inaccessibility to many readers, increased computational load (though this may not prove important), and the larger number of parameters to be estimated. The entire approach is, apparently, a novel extension of traditional learning curve formulations; as such, its reception and endorsement by other researchers is not assured.

User Issues

To be successful as the basis of a decision support system, a model must provide information that is both accurate and pertinent to the training design problem at hand. Furthermore the effort required to obtain the information must be commensurate with the value of the results. No system will solve training design problems without some effort from the user. However, systems that require substantial effort must provide results of similar value.

Relevance

Relevance is a primary concern in the evaluation of any decision aid. Ensuring relevance requires contact with potential users of the aid. At this stage in the development process, is too early to determine the relevance of the decision model presented in this report. However, it is critical that before the model is developed further, potential users are allowed to evaluate the conceptual model.

Data Requirements

The skill-based training system design model requires considerable data. Many of the data requirements can be met by standard task analytic methods, but other requirements are outside of the scope of traditional task analysis. This discussion focuses on three types of data required by the model: (a) detailed process descriptions, (b) quantitative estimates, and (c) cost estimates.

The primary role of the SME in the model is to provide detailed descriptions of how general abilities are applied to specific tasks. In Air Traffic Control, for example, the SME would be required to determine whether the controller senses potential aircraft conflicts using an analog visual model of the airspace, or whether the controller performs a more analytical analysis of aircraft information. This information is obviously critical for the design of training for this activity. It is equally obvious that the SME is the only possible source of the required information. The procedure to obtain information from the SME in the model extends traditional task analytic methods that describe tasks, subtasks, and task elements. By carefully eliciting the required information so that the effects of SME biases are minimized, it should be possible to obtain the detailed

descriptions of skill performance required by the model with reasonable confidence.

Quantitative estimates are inherently more difficult to obtain than verbal data or ordinal comparisons, because a single quantitative estimate has the information of several ordinal comparisons. The process of obtaining quantitative estimates has been refined over 60 years of scaling research, and it should be possible to develop scaling procedures for most quantitative variables that are both reasonably accurate and easily applied. These methods include procedures that allow the researcher to infer the quantitative information that is present in rank orders of sets of objects, procedures that compare objects to pre-scaled verbal anchors, or procedures in which the judge compares specially chosen combinations of objects. Thus, although obtaining estimates of quantitative parameters is difficult because of the information those estimates contain, there are a variety of procedures available to obtain these estimates in a relatively painless fashion.

Estimates of cost may be the most difficult data requirements of the model. In fact, it is probably the difficulty of obtaining accurate cost estimates that leads most procedures for training-system design to ignore cost until most (or all) instructional decisions have been made. The reasons for the difficulty in obtaining cost information are manifold. Among these difficulties are problems in determining which cost elements to include in the estimate, the near impossibility in obtaining an accurate cost accounting for existing training systems, and the difficulty in predicting the future cost of technology. One aspect of the model that makes the cost-estimation problem easier is that the model requires that cost be measured only on a ratio scale. That is, the costs may reflect relative costs, as compared to an arbitrary standard. Since only relative costs are required, we recommend that a relative scaling procedure be used to obtain costs. Knerr, Morrison, Mumaw, Sticha, Blacksten, Harris, and Lahey (1987) applied such a procedure to estimate the cost of developing instructional support features. This procedure was adapted by Braby, Charles, Sylla, Ramesh, Willis, and Hunter (1988) for design of training-device instructor/operator station.

Research Issues

The skill-based training system design model is based on a combination of problem analysis and empirical research. Neither of these two methods is sufficient without support from the other. There are two primary areas where the need for further empirical research is obvious: (a) transfer of training between tasks and skills, and (b) effect of limited attention and overload on learning. Further research in these areas is critical to further our understanding of the capabilities of skill-based training.

Transfer of Training

Skill training is based on the assumption that it is possible to get significant transfer of training between activities trained under substantially

different conditions. Determining the extent to which such transfer is possible and the conditions under which it will occur touches on an issue that has been alive in the psychological literature for nearly a century. Recent theories of transfer of training, such as Kieras and Bovair (1986) postulate that transfer of training occurs at the microscopic level of the individual production rule. Our analysis has been consistent with this theory in the sense that we conduct a skill analysis down to the level of the specific skill, which specifies both the general ability involved and the domain-specific knowledge on which the ability operates.

However, it is not feasible to continue the skill analysis to the level of the single production rule; the time required for such an analysis would be well beyond the scope of any task-analytic effort. Our approach to transfer of training uses a very general characterization of transfer as the asymptote of a function, or equivalently as a slope of a linear transfer function. It is difficult to estimate the accuracy of our simple assumption. One goal of the skill characterization is to provide a heuristic for estimating transfer of training. It is not clear that the skill characterization has sufficient depth at this point to aid transfer estimation.

The problem of transfer of training is especially critical when one must allocate training resources among skill-training and task-training options. In this case transfer may occur between tasks, between skills, or between tasks and skills. Finding the optimal allocation of training resources requires us to understand how these sources of transfer balance out for any allocation option. As the previous discussion indicated, accounting for transfer of training is a potential source of substantial model complexity. A thorough empirical research program is required to determine the appropriate rules to characterize transfer of training.

Attention and Overload

We have assumed that the attention required to perform or learn a task decreases in proportion to the level of performance. This assumption reflects general empirical results and theoretical formulations, but the specific nature of the assumption is completely ad hoc. There is reason to believe that attention requirements decrease at a slower rate than performance improves, contrary to our assumptions. There is also reason to postulate that controlled and automatic processes are separate processes, which may develop independently, or as a result of a specific knowledge compilation process. Either of these changes would increase the complexity of the model significantly. This area of skill acquisition is one where current research trends are likely to produce useful results. It is important that these research programs continue, and that training-system designers are informed of these results.

Conclusions and Recommendations

We have developed an integrated framework for making decisions regarding the design of skill-based training systems. The decision-making procedure addresses the identification of skills and training strategies, the design of training

devices, and the allocation of training resources to skill-based and task-based training alternatives. Underlying the decision model are a skill characterization and cost-effectiveness model that represent many of the factors that are important in evaluating skill training options.

The need for a long-term research effort is obvious from the development at this point. There are several topics for further research which would enhance our abilities to predict the cost and effectiveness of skill training, including research on transfer of training from skill training to task performance, and research on the effects of attention and overload.

Clearly, the model is in its infancy. Although grounded in a strong body of research, we know that the accuracy with which we may extrapolate from theory and prior experience is limited. The model makes several assumptions that will need to be tested and revised. Its usability in the field also must be studied and enhanced. We believe that the best way to proceed is to apply the model to several task domains chosen not for high probability of success, but rather on the basis of job complexity and training need. Researchers need to work with training developers to find ways to tailor the model to their needs. Through this iterative process the Army can develop the tools to develop more effective and efficient training.

REFERENCES

Adams, J. A. (1960). Part trainers. In G. Finch (Ed.), Educational and training media: A symposium (pp. 129-149). Washington, DC: National Academy of Sciences, National Research Council.

Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. Psychological Bulletin, 101, 41-74.

Ammerman, H.L., Bergen, L.J., Davies, D.K., Hostetler, C.M., Inman, E.E., & Jones, G.W. (1987). FAA air traffic control operations concepts. Vol. VI: ATRCC/HOST on route controllers (Report No. DOT/FAA/AP-87-01). Washington, D.C.: U.S. Department of Transportation, Federal Aviation Administration.

Anderson, J. R. (1983). The architecture of cognition. Cambridge, MA: Harvard University Press.

Anderson, J. R. (1985). Cognitive psychology and its implications. New York: W. H. Freeman and Company.

Anderson, J. R., Conrad, F. G., & Corbett, A. T. (1989). Skill acquisition and the LISP tutor. Cognitive Science, 13, 467-505.

Boff, K. R., & Lincoln, J. E. (1988). Engineering Data Compendium: Human Perception and Performance, Wright-Patterson AFB, OH: Harry G. Armstrong Aerospace Medical Research Laboratory.

Braby, R., Charles, J., Sylla, C., Ramesh, R., Willis, R., & Hunter, D. (1988). Instructor considerations in the design of optimal training devices (Final Report). Orlando, FL: Eagle Tech, Inc.

Card, S. K., Moran, T. P., & Newell, A. (1983). The psychology of human-computer interaction. Hillsdale, NJ: Erlbaum.

Cronholm, J. N. (1985). The optimization of training systems. Proceedings of symposium on the transfer of training to military operational systems (pp. 237-259). Brussels, Belgium: NATO.

Department of Defense (1986). Glossary of Training Device Terms (MIL-HDBK-220B). Washington, DC: Author.

Eggemeier, F. T., Fisk, A. D., Robbins, R. J., & Lawless, M. T. (1988). Application of automatic/controlled processing theory to training tactical command and control skills: II. Evaluation of a task analytic methodology. *Proceedings of the Human Factors Society 32nd Annual Meeting*, 1232-1236.

Fisk, A. D., & Eggemeier, F. T. (1988). Application of automatic/controlled processing theory to training tactical command and control skills: 1. Background and task analytic methodology. *Proceedings of the Human Factors Society 32nd Annual Meeting*, 1227-1231.

Fitts, P. M. (1964). Perceptual-motor skill learning. In A. W. Melton (Ed.), *Categories of human learning*. New York: Academic Press.

Fleishman, E. A. (1966). Human abilities and the acquisition of skill. In E. A. Bilodeau (Ed.) *Acquisition of skill*. New York: Academic Press. pp. 147-167.

Fleishman, E. A. (1967). Performance assessment based on an empirically derived task taxonomy. *Human Factors*, *9*, 349-366.

Fleishman, E. A. (1982). Systems for describing human tasks. *American Psychologist*, *37*, 821-834.

Fleishman, E. A., & Quaintance, M. K. (1984). *Taxonomies of human performance*. New York, NY: Academic Press, Inc.

Gagné, R. M. (1968). *A systems approach to adult learning* (Technical Report 15, 1-14). Washington University: Department of Psychology.

Gagné, R. M. (1974). *Essentials of learning for instruction*. New York, NY: Holt, Rinehart & Winston.

Gagné, R. M. (1975). *Essentials of learning for instruction*. Hinsdale, IL: The Dryden Press.

Gopher, D., Weil, M., Bareket, T., & Caspi, S. (1988). Fidelity of task structure as a guiding principle in the development of skill trainers based upon complex computer games. *Proceedings of the Human Factors Society 32th Annual Meeting* (pp. 1266-1270). Santa Monica, CA: Human Factors Society.

Halley, R., Jr., Hooks, T., Jr., Lanford, H. G., & Nowell, L. H. (1981). *Behavioral objectives for air intercept controller prototype training system* (Technical Report NAVTRAEQUIPCEN 78-C-0182-1). San Diego, CA: Logicon, Inc., Tactical & Training Systems Division.

Kieras, D. E., & Bovair, S. (1986). The acquisition of procedures from text: A production-system analysis of transfer of training. Journal of Memory and Language, 25, 507-524.

Knerr, C. M., Morrison, J. E., Mumaw, R. J., Stein, D. J., Sticha, P. J., Hoffman, R. G., Buede, D. M., Holding, D. H. (1986). Simulation-based Research in part-task training (Report No. AFHRL-TR-86-12). Brooks AFB, TX: U.S. Air Force, Air Force Human Resources Laboratory.

Knerr, C. M., Morrison, J. E., Mumaw, R. J., Sticha, P. J., Blacksten, H. R., Harris, C., & Lahey, G. (1987). Analysis and design of part-task training for aircrew skills (HumRRO Report FR-PRD-87-2). Alexandria, VA: Human Resources Research Organization.

Mallamad, S. M., Levine, J. M., & Fleishman, E. A. (1980). Identifying ability requirements by decision flow diagrams. Human Factors, 22, 57-68.

Means, B. M., & Gott, S. P. (1988). Cognitive task analysis as a basis for tutor development: Articulating abstract knowledge representations. In Psotka, Massey, & Mutter (Eds.), Intelligent tutoring systems: Lessons learned. Hillsdale, NJ: Erlbaum.

Miller, R. B. (1971). Development of a taxonomy of human performance: Design of a systems task vocabulary (Tech. Rep. AIR-72 6/2035-3/71-TRII). Silver Spring, MD: American Institutes for Research, March, 1971.

Myers, G. L., & Fisk, A. D. (1987). Application of automatic and controlled processing theory to industrial training: The value of consistent component training. Human Factors, 29, 255-268.

Naylor, J. C. (1962). Parameters affecting the relative efficiency of part and whole training methods: A review of the literature (NAVTRADEVCEN 950-1, AD-275 921). Port Washington, NY: U.S. Naval Training Device Center.

Office of the Assistant Secretary of Defense (Force Management and Personnel) (1989). Military Manpower Training Report for FY 1990. Washington, DC: Author.

Newell, A. & Rosenbloom, P. (1981). Mechanisms of skill acquisition and the law of practice, in J.R. Anderson (Ed.), Cognitive skills and their acquisition. Hillsdale, NJ: Erlbaum.

Perkins, D. N. & Salomon G. (1989). Are cognitive skills context-bound? Educational Researcher, 18, 16-25.

Ross, D.T. & Schoman, K.E., Jr. (1977). Structured analysis for requirements definition. IEEE Transactions on Software Engineering, SE-3.

Schneider, W. (1985). Training high-performance skills: fallacies and guidelines. Human Factors, 27, 285-300.

Schneider, W. & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search and attention. Psychological Review, 84, 1-66.

Schneider, W., Vidulich, M. A., & Yeh, Y. Y. (1982). Training spatial skills for air-traffic control. Proceedings of the 26th Annual Meeting of the Human Factors Society (pp. 10-14). Santa Monica, CA: Human Factors Society.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 84, 127-190.

Smith, B.A., Waters, B.K., & Edwards, B.J. (1975). Cognitive pretraining of the T-37 overhead traffic pattern (AFHRL TR-75-72, AD A026 118). Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory.

SofTech, Inc. (1981). Integrated computer-aided manufacturing (ICAM). Architecture Part II. Volume IV - Function modeling manual (IDEF0). Waltham, MA: Author.

Sticha, P. J., Blacksten, H. R., Buede, D. M., Singer, M. J., Gilligan, E. L., Mumaw, R. J., & Morrison, J.E. (1988). Optimization of simulation-based training systems: Model description, Implementation, and Evaluation (HumRRO Report FR-PRD-88-26). Alexandria, VA: Human Resources Research Organization.

Vidulich, M., Yeh, Y., & Schneider, W. (1983). Time compressed components for air intercept control skills. Proceedings of the Human Factors Society 27th Annual Meeting (pp. 161-164). Santa Monica, CA: Human Factors Society.

Welford, A. T. (1968). Fundamentals of skill. London: Methuen. (cited in Adams, J. A. (1987). Historical review and appraisal of research on the learning, retention, and transfer of human motor skills. Psychological Bulletin, 101, 41-74.)

APPENDIX
DEFINITIONS OF GENERAL ABILITIES

These definitions of the general abilities are drawn primarily from Fleishman & Quaintance (1984) and Miller (1971). Most of the definitions are quoted directly from the cited sources; any adaptations are noted. Definitions without attribution are combined from several sources.

Psychomotor Abilities

Control precision. The ability to make fine, highly controlled muscular movements required to adjust the position of a control mechanism. Examples of control mechanisms are joy sticks, levels [sic.], pedals, and rudders . . . This ability is most critical where adjustments must be rapid, but precise (Fleishman & Quaintance, 1984, p. 164).

Dexterity. The ability to make skillful, well directed arm-hand movements in manipulating fairly large objects under speeded conditions (Fleishman & Quaintance, 1984, p. 165).

Multilimb coordination. The ability to coordinate the movement of a number of limbs simultaneously (Fleishman & Quaintance, 1984, p. 164).

Rate control. [This ability] involves the timing of continuous anticipatory motor adjustments relative to changes in speed and/or direction of a continuously moving target or object (Fleishman & Quaintance, 1984, p. 164).

Reaction speed. This ability represents the speed with which the individual can provide a single motor response to a single stimulus when it appears (Fleishman & Quaintance, 1984, p. 164).

Aiming. The ability to make highly accurate, restricted hand movements requiring precise eye-hand coordination (Fleishman & Quaintance, 1984, p. 165).

Response orientation. This is the ability to select and initiate the appropriate response relative to a given stimulus in the situation where two or more stimuli are possible and where the appropriate response is selected from two or more alternatives. The ability is concerned with the speed with which the appropriate response can be initiated and does not extend to the speed with which the response is carried out (Fleishman & Quaintance, 1984, pp. 324-5).

Perceptual Abilities

Detection. [The ability to sense] the presence or absence of a cue or condition requiring that some form of action should be taken by the system . . . Detecting results in sensing a stimulus to which attention will be paid (Miller, 1971, cited in Fleishman & Quaintance, 1984, p. 442).

Selective attention. This is the ability to perform a task in the presence of distracting stimulation or under monotonous conditions without significant loss in efficiency . . . Under conditions of distracting stimulation, the ability involves concentration on the task being performed and filtering out of the distracting stimulation. When the task is performed under monotonous conditions only concentration on the task being performed is involved (Fleishman & Quaintance, 1984, p. 323).

Spatial reasoning. The ability to make inferences about the absolute or relative positions and velocities of objects in space.

Pattern recognition. [The ability to characterize] a message by type or source . . . [to identify] an object or entity and apply some label to it (Miller, 1971, cited in Fleishman & Quaintance, 1984, p. 444).

Visualization. The ability to imagine how something will look when it is moved around or when its parts are moved or rearranged. It requires the forming of mental images of how patterns or objects would look after certain changes, such as unfolding or rotation. One has to predict how an object, set of objects, or pattern will appear after the changes are carried out (Fleishman & Quaintance, 1984, p. 462).

Discrimination. [The ability to] classify or differentiate an entity in terms of gross-level grouping or set membership, frequently on the basis of only a limited number of attributes (Ammerman, et al., 1987).

Cognitive Abilities

Verbal comprehension. The ability to understand language. It is concerned with the understanding of individual words as well as words as they appear in context, i.e., in sentences, grammatical patterns and idiomatic phrases (Fleishman & Quaintance, 1984, p. 322).

Quantitative reasoning. The ability to reason abstractly using quantitative concepts and symbols. It encompasses reasoning

through mathematical problems in order to determine appropriate operations which can be performed to solve them. It also includes the understanding or structuring of mathematical problems. The actual manipulation of numbers is not included in this ability (Fleishman & Quaintance, 1984, p. 322).

Meta-cognition. The ability to monitor internal learning and cognitive processes.

Inductive reasoning. The ability to find the most appropriate general concepts or rules which fit sets of data or which explain how a given series of individual items are related to each other. It involves the ability to synthesize disparate facts; to proceed logically from individual cases to general principles (Fleishman & Quaintance, 1984, pp. 322-3).

Analogical reasoning. The ability to formulate a solution to a problem by comparing the object of the problem with another object (the analog) that has similar properties, and performing actions on the object of the problem that correspond to actions that would be performed on the analog.

Prioritizing. [The ability to order] events in sequence; establishing priorities (Ammerman, et al., 1987).

Information recall. The ability to remember information, such as words, numbers, pictures, and procedures. Pieces of information can be remembered by themselves or with other pieces of information (Fleishman & Quaintance, 1984, p.461).

Backward chaining. The ability to formulate a solution to a problem by analyzing goals into subgoals, and selecting actions that meet the subgoals.

Abstraction. The ability to determine the formal or logical characteristics of a situation or object.

Computation. The ability to manipulate numbers in numerical operations; for example, add, subtract, multiply, divide, integrate, differentiate, etc. The ability involves both the speed and accuracy of computation (Fleishman & Quaintance, 1984, p. 322).

Time sharing. The ability to shift back and forth between two or more sources of information (Fleishman & Quaintance, 1984, p. 463).

Deductive reasoning. The ability to apply general concepts or rules to specific cases or to proceed from stated premised to their logical conclusions (Fleishman & Quaintance, 1984, p. 322).

Planning. [The ability to predict] what future sets of conditions will occur and what responses to make to them and in what order (Miller, 1971, cited in Fleishman & Quaintance, 1984, p.452).

Knowledge compilation. The ability to convert declarative knowledge about how to perform an activity into a procedural representation that produces an increase in performance speed (adapted from Anderson, 1983).

Forward chaining. The ability to formulate the solution to a problem by selecting actions that reduce the scope of the problem, until the goal is attained.

Categorization. The ability to classify data, information, or intelligence according to its source, format, purpose, or content in order to organize messages into meaningful groups, or in order to selectively retrieve them for decision making and control (Miller, 1971, cited in Fleishman & Quaintance, 1984, p. 446).